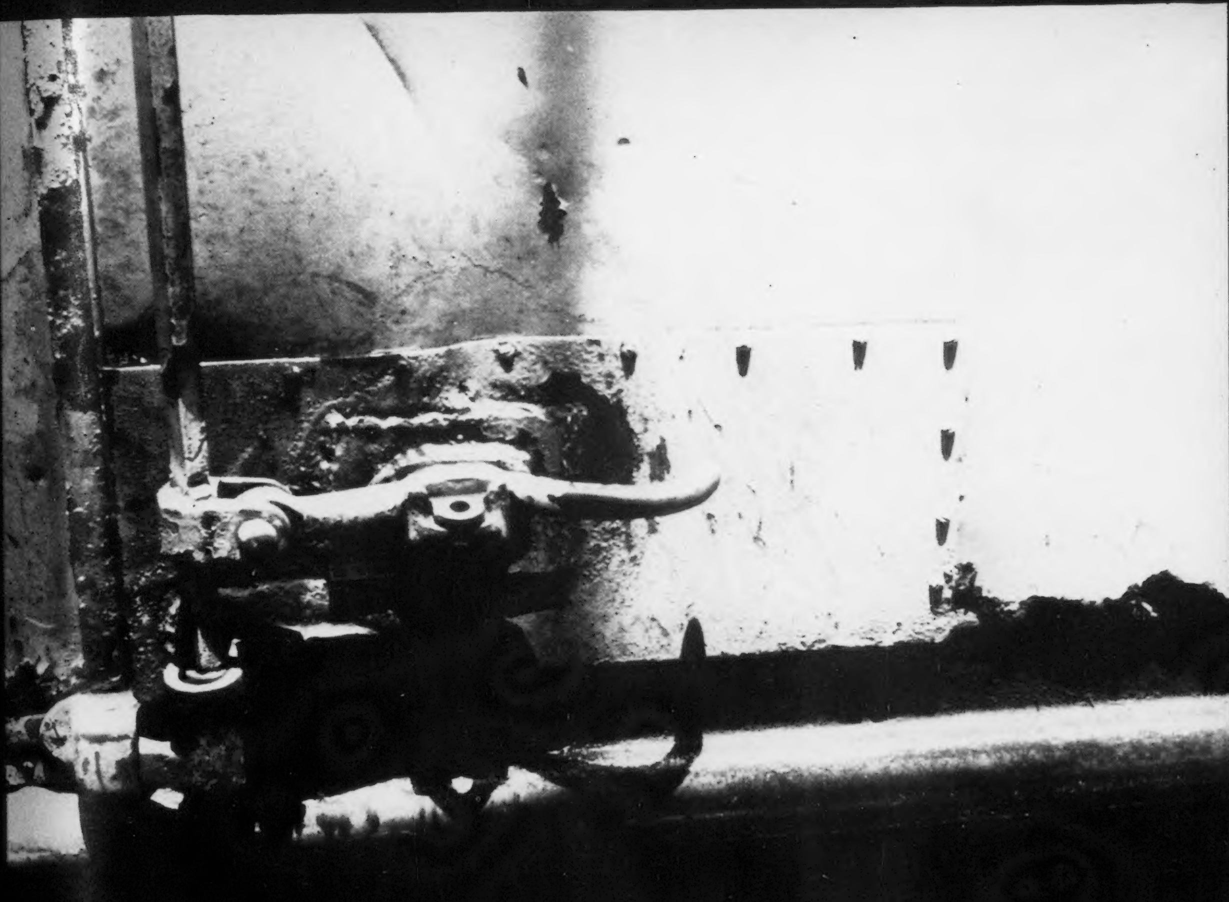
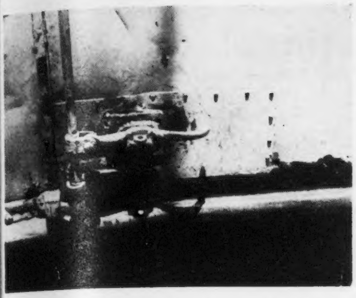
Corrosion

NATIONAL ASSOCIATION OF CORROSION ENGINEERS





THIS MONTH'S COVER—This milk delivery truck door shows the ravages caused by water from melting ice. Body has been perforated in lower left and eaten away to the right of the latch reinforcing plate. An effort has been made to patch the latch by welding. Damage to coating is visible at other points. Trucks using ice as refrigerant suffer heavy damage from water.

☆

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(b) To provide forums and media through which experiences with corrosion and its prevention may be reported, discussed and published for the common good.

(c) To encourage special study and research to determine the fundamental causes of corrosion, and to develop new or improved techniques for its prevention.

(d) To correlate study and research on corrosion problems among technical associations to reduce duplication and increase efficiency.

(e) To promote standardization of terminology, techniques, equipment and design in corrosion control.

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(g) To foster cooperation between individual operators of metallic plant and structures in the joint solution of common corrosion problems.

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Corrosion

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Topic of the Month

Chlorine Dioxide Generation— A "High Brightness" Corrosion Problem

By H. O. TEEPLE*

IN THE pulp and paper industry, a number of mills have installed chlorine dioxide bleaching systems[1] to supply the demand for high brightness, high strength pulps.[2] There are a number of processes[3] commercially available, all involving rather severe corrosion problems. These problems, briefly stated, consist of mixtures of methanol, sulfurous, or sulfuric acid, together with chlorine dioxide, chlorine and other reaction products at temperatures up to 150 F.

At the outset, the number of suitable materials of construction is limited. However, because of the rather free interchange of information within the pulp and paper industry and the cooperation of allied industry, substantial progress has been achieved in the economical solution of the problems.

As a consequence, a number of non-metallic and metallic materials have been found to give economical performance in the chlorine dioxide generating plants. Such materials as acid-proof stoneware, graphite and plastics[1, 3, 4] have been used extensively where their physical or mechanical properties are favorable. For a number of other applications it has been found desirable to use metallic materials such as Durichlor, Hastelloy C, Chlorimet 3 and some other proprietary alloys.

A corrosion survey was made[5] to establish corrosion rates for a number of metallic materials. Some of the results are shown in Table 1. In general, the data supported service experience in that Durichlor, Hastelloy C and Chlorimet 3 are fairly satisfactory, with the austenitic stainless steels not dependable because of high weight loss corrosion rates or susceptibility to severe localized attack. Some proprietary alloys are fairly satisfactory in some instances. Materials, such as bronze, ferritic stainless steels, Monel, Inconel and aluminum are not satisfactory.

Thus it can be seen that a combination of an exchange of technical information, cooperation, and the judicial use of nonmetallic and metallic materials has resulted in a significant alleviation of a "high brightness" corrosion problem.

* The International Nickel Co., Inc., New York, N. Y.

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4. Latest Development in the Use of Plastic Materials of Construction. R. B. Seymour and M. H. Smith. *Paper Trade J.*, **137,** No. 25, 33-36 (1953).
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TABLE 1

Test A: A field test for 351 hours in the top of a chlorine dioxide reaction tower. The solution was a mixture of 60° Be sulfuric acid, sodium chlorate, methanol and chlorine dioxide at 135° F. The flow rate was 60 gpm.

Test B: A field test for 351 hours in a receiver tank containing a solution of 5 gpl chlorine dioxide, the pH was 2 to 3.5, and the temperature was 36° F.

	Corrosion Rates, Inch Penetration per Year	
	Test A	Test B
LaBour R55	.002	.0036
Durichlor	.003	.0001
Chemical Lead	.006	.21
Hastelloy C	.013	.050
Chlorimet 3	.020	.014
Durimet 20	.027 (a)	.0007
Type 316 S.S.	.15 (b)	.0001

(a) 0.059-inch maximum pitting.
(b) Spec. perforated 0.031-inch.

Organization and Activity Of the Corrosion Control Group Of a Large Public Utility★

By JAMES W. McAMIS

A NUMBER of articles have been written which deal with corrosion control on transmission pipe lines. This is only natural since most of the early work in the field has been done by men affiliated with transmission companies. However, since my work has been entirely with a distribution company, the following material may be of more interest to distribution men than to transmission men; but it is thought that some of the suggestions will be helpful to men in both lines of work.

The article will discuss problems arising in and the solutions obtained by one large utility company which was founded over 106 years ago. The underground system is composed of over 2900 miles of mains piping with service take-offs for approximately 335,000 meters. The system serves the District of Columbia and suburbs in Maryland and Virginia, each governed by a separate utility commission, as well as seven local governments with individual plumbing, water, sewage and highway departments.

Lines Under Heavily Traveled Streets

The low-pressure piping system is largely cast iron, portions of it more than 90 years old and is under heavily traveled streets, alongside sewer, water, telephone, electric power and streetcar underground lines.

Other large portions of the system consist of bare steel mains intermixed with cast iron and with mill wrapped steel first used in 1941. Current installations of all service pipes and practically all steel mains are made with mill wrapped steel pipe.

Also included are one 12-inch bare, one 16-inch partly bare and partly wrapped, one 16-inch wrapped and one 22-inch wrapped steel transmission lines between two pipe line metering stations and three pumping and/or regulating stations. These lines average approximately 22 miles in length and each feeds numerous small distribution networks through district regulators.

The territory is approximately 35 miles long by 30 miles wide with rapid growth occurring in all directions at the outskirts, as well as in the less densely populated areas nearer the center. Indicative of the growth occurring in this system, the Corrosion Control Group processed approximately 1100 sketches involving approximately 950,000 feet of new and replacement mains during 1954. The number of contractor crews assigned to new mains extensions has more than doubled since last April.

The company first used a corrosion consultant in 1941 (and the practice has been continued). In 1950 responsibility for all pipeline corrosion control activities was assigned to a staff engineer, assisted by staff assistant, both already on the payroll and with a basic background for the assignment.

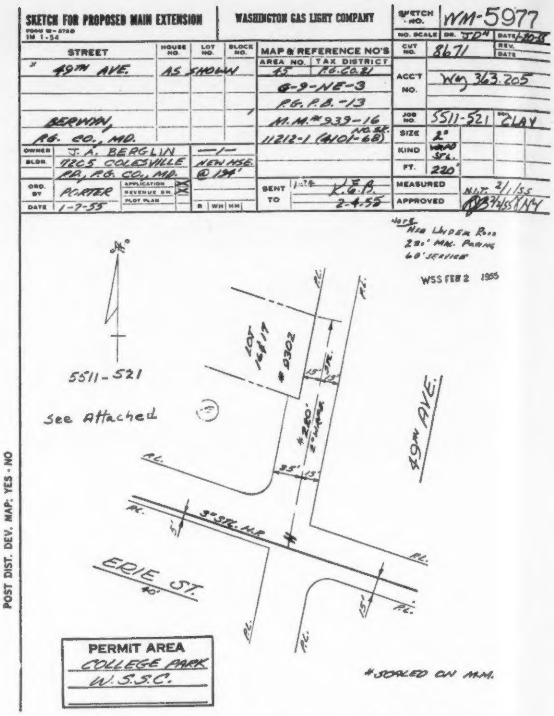

Figure 1—Sketch for proposed main extension. Broken line indicates proposed main. Insulating joint shown between old bare steel and coated new lines.

JAMES W. McAMIS—Staff engineer for the Street Department of Washington Gas Light Company. Since joining the company in 1935 as clerk he has worked in various engineering jobs including Utilization-Appliance Testing Laboratory and Customer Appliance Service Department. In his present position he is responsible for corrosion control practices and procedures for his firm. Mr. McAmis received a AB in chemistry from Tusculum College in 1932. He has ben a member of NACE since 1952.

Abstract

Methods developed to accumulate information and direct the corrosion control activities of a utility with 2900 miles of piping with 335,000 meters on service take-offs are discussed. Data are collected in the form of maps, recommendations and drawings of installations. Available information on relative corrosivity of certain areas is plotted to a central map. The Corrosion Control Group generally supervises mitigation measures, with actual work under foremen, who also are responsible for training personnel. Testing of the effectiveness of installations has been limited by lack of time and personnel, but more is expected to be done soon. Use of holiday detectors is recommended.

★ A paper presented at the Eleventh Annual Conference, National Association of Corrosion Engineers, Chicago, Ill., March 7-11, 1955.

JOB NO. See Dwg. ____________

CORROSION CONTROL GROUP RECOMMENDS:

A - Use insulated coupling at all tie-ins between C. I. pipe and steel pipe. Coat couplings with primer and hot enamel.

B - Bond or weld all connections, including services. Check with Corrosion Control Group at the start of this job, and install Magnesium Anodes as group directs. (See Drawing C,73-SD, E-71-SD, E-69-SD)

C - Install ____-______ Insulating Couplings with test wires, as shown (See Drawing C-38-SD)
No. Size

D - Install Insulating Joints on all meter installations.

E - Use wrapped pipe only.

F - Check the coating of all ____ pipe and connections for holidays, using an approved type Holiday Detector. All holidays found are to be patched and retested.

G - Install ____ pair(s) of test wires, with 100' 0" distance between points, as shown, (See Drawing E-72-SD). Contact Corrosion Control Group for exact location and tags for these wires.

H - Coat with hot enamel or approved cold coating all bolts used at the C. I. pipe joints. Coat with hot enamel all Dresser couplings and steel tees and crosses used.

Effective Date 10-8-52 Form Dwg., E-14-SS

Figure 2—Corrosion Control Group Recommendation form. Letter designation for applicable procedures is circled. Other procedures "lined-out."

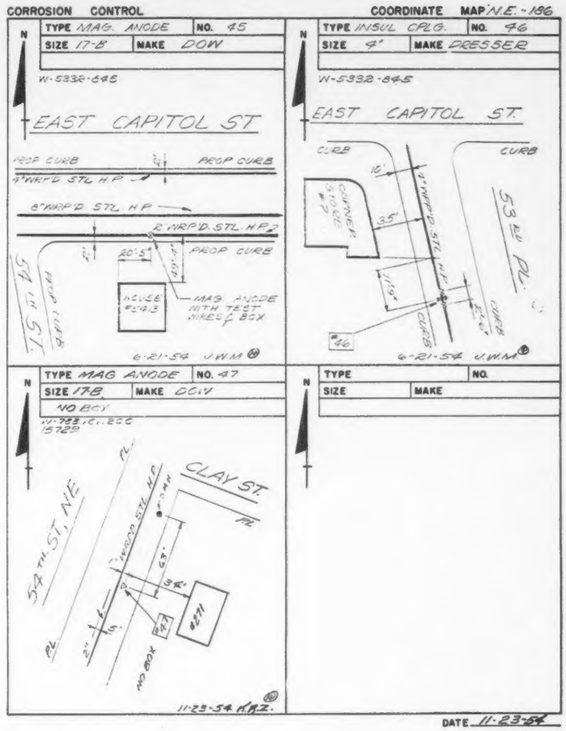

Figure 3—Corrosion control drawing. Individual controls are numbered and exact location measurements given. Prints are used in field to locate items for tests.

Use of Corrosion Engineer Recommended

An increasing number of utility managements are taking steps to allay corrosion of their underground facilities. This paper will not go into detail regarding personnel requirements, since company size, growth, use of wrapped pipe and other conditions will control the size of the unit. Corrosion control in a small utility may require only a part of the time of one man, while a larger company may require many more on the same work. It is suggested that any company contemplating a corrosion control set-up obtain the services of a competent corrosion engineer, either as a part of the organization or on a consulting basis. If the man selected to head the program is already employed within the company, he should be an engineer with chemical and/or electrical training. In addition, it is advisable to have him attend at least one corrosion short course, several of which are available each year through National Association of Corrosion Engineers in co-operation with recognized colleges or universities.

One of the first duties of this group is to determine the scope of corrosion control work to be accomplished. Since it may act in a staff or advisory, rather than a line or direct supervisory capacity, it will be necessary to establish a system for reviewing jobs on which corrosion control recommendations are required. In the writer's organization this is accomplished by routing a sketch of proposed main extension (Figure 1) for each proposed extension, replacement or revision through the group. A recommendation for the control of corrosion on any line normally would result from a preliminary field survey. However, due to volume of work, it is rarely practical; so in the author's company a substitute plan has been devised. Recommendations are prepared in the office for each job, with minor adjustments possible on a basis of a field survey of selected jobs while construction is in progress.

Corrosion control recommendations are indicated on a "Corrosion Control Group Recommends" sheet (Figure 2), which includes more than 95 percent of the control practices usually specified and attached to the job sketch. Proposed insulating joint locations and other special instructions are marked on the sketch, which is returned to Mains Planning and Drafting Section of the Engineering Department for inclusion on construction drawings.

Coordinate Record System Used

In order to establish a basis for these recommendations, a coordinate record system, already in use by the engineering department was adapted for corrosion control work. This coordinate system consists of approximately 800 large scale maps (50 feet = 1 inch for District of Columbia and 200 feet = 1 inch for other sections) which indicate locations, size and type of mains within their boundaries. The maps, which are folded and filed in a "legal size" folder, are used to show the system as it exists, both protected and unprotected. The file was started in 1950 with the minimum prints required to plot protection installations and replacements made since 1947, when real emphasis was first placed on corrosion control. This eliminates posting by the Corrosion Control Group of unprotected jobs made prior to the initial corrosion control installation in any coordinate area. All postings to these maps are made by a clerk or staff member of our group.

It will be seen by reference to the corrosion control recommendation sheet (Figure 2) that items B recommends, "Notify Corrosion Control Group at the start of this job, and install Magnesium Anodes as group directs." Upon notification at start of a job so marked, a representative of the corrosion control group visits the job and measures earth resistivity with a meter by the four point method. Anode instal-

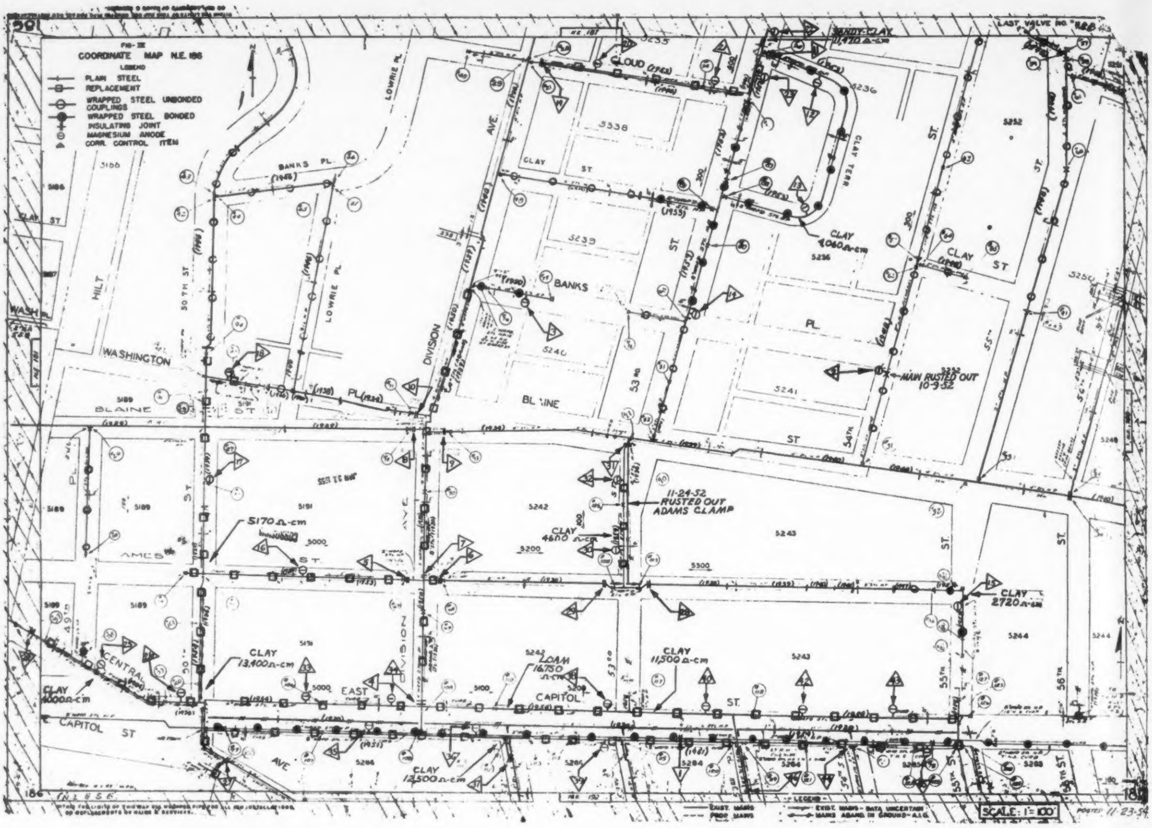

Figure 4—Coordinate Map (NE 186). Copy of file map shows mains piping layout, age, material, type of joint, control items, etc. May be used in field for overall picture of entire area. Color codes normally used to facilitate use in locating coated pipe, replacements, etc.

lation and spacing is specified where soil resistivity is 15,000 ohm/cm or less. In some instances, regardless of soil resistivity measurement, anodes may be specified based on special soil conditions. The location and value of each soil resistivity measurement is also posted on the file copy of the coordinate map. Thus, the map, (of which Figure 4 is typical) showing approximate location of insulating joints, anodes, rectifiers, test wires, pipe location and soil resistivity at definite locations, is available for future reference and test purposes.

Upon completion of main extensions, replacements, off-sets, etc., using corrosion control installations, the construction field notes are so marked by a field clerk. As they are posted to the master coordinate map, a Corrosion Control Drawing (Figure 3), size 8½ x 11 inches is prepared showing exact measurements and a Corrosion Control Item number assigned to the installation. Each corrosion control drawing shows four installations. Consecutive numbers are assigned to each coordinate and, as an item is added, a revised corrosion control print is prepared showing the new item. These prints are filed in a loose leaf book according to coordinate map and item number, after the information is posted to the file copy of the coordinate map.

Other Data Posted Also

Completed main replacements, leak band repairs and location of test holes with data on depth of cover, corrosion pit depth, soil conditions and other pertinent information also are posted to the map. When detailed survey data are obtained, these original sheets also are placed in the file folder with the coordinate map to provide additional information on stray current magnitude, protection surveys, insulating joint resistance and proposed replacement sketches. This information is generally too complex for posting to the coordinate map.

Corrosion experience involving services is not posted to the map. However, a separate card file is maintained, by coordinate area, listing the street address of each service replaced due to corrosion. Original installation date, replacement date and service life in years for each service is recorded on this Replacement Service Record. A periodic review of these records is used as a guide to highly corrosive areas and need for investigation for further leak survey and scheduled replacements.

In addition to furnishing a guide by which new mains specifications are written, information in the above files is also reviewed in considering the replacement of mains. Upon notification by a public authority that paving activity is planned at a certain location, all gas piping within the paving limits is surveyed for leakage by the bar-test method over the mains and services. The same type of survey may result from report of gas odor in the street or from conditions found on other maintenance jobs. Where leakage is indicated, the Corrosion Control Group, from data on the "Leak

Survey Sketch" and information in the two files mentioned above (Coordinate Map and Service Replacement Card), recommends 1) replacement of the main, 2) digging test holes to inspect the pipe, or 3) repair leakage found. When test holes are dug, the data obtained are studied with other available information. If replacement is recommended, a sketch showing limits of recommended replacement and proposed corrosion protection is prepared. When repairs are recommended, the available file data usually determine amount and type of cathodic protection to be used.

Corrosive Areas Easily Identified

Summarizing the information contained on the coordinate maps and the Replacement Service Record file on a system-wide map provides an easy means of identifying corrosive areas (Figure 5). This summary has been very useful, even though no experience data is available for some sections where corrosion leaks have not been experienced because of the newness of the system or absence of extremely corrosive soil. Since records cover less than five years, there may be some highly corrosive sections which do not show on the map. However, as new experience is gained through leakage surveys, soil resistivity measurements, etc., it will be kept up-to-date. In time, with continued posting of information to the coordinate maps, these records will provide an accurate picture of conditions existing in the field almost as well as a preliminary field survey.

Map Used for Recommendations

In lieu of the preliminary field survey, Corrosion Control Recommendations are made on a basis of the information obtained from the Coordinate Map and other information contained in the folder, the Replacement Service Record file and in line with standard operating policies and procedures. In some instances, usually on short extensions or when sufficient corrosion experience is available in the files, it is possible to eliminate the field survey; but, whereever any doubt exists, a corrosion control representative determines installation requirements in the field while work is in progress. The omission of field inspection on work in new subdivisions and in "advance of paving" is seldom advisable, even in areas of known high resistivity soil, due to rapid changes in soil resistivity possible with earth moving activities required to establish grade. For example, on one service insert replacement, three excavations were made. At the main in the center of the street, a clay soil with resistivity of 1200 ohm/cm was found. At the stopcock, behind the curb, soil contained a high percentage of sand and measured over 10,000 ohm/cm. Approximately eight feet inside the curb there was very little sand and the resistivity had changed to 3500 ohm/cm. Such rapid changes are not uncommon and increase corrosion rates.

From the field observation of soil conditions, soil resistivity measurements and piping lay-out as shown on the Construction Drawing, the corrosion control representative advises the foreman as to magnesium anode placement. Guided by a pre-determined schedule, based on soil resistivity and pipe

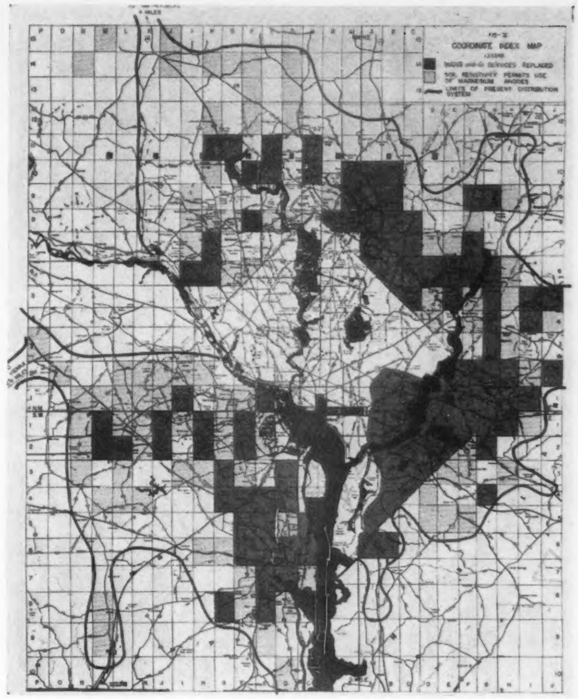

Figure 5—Coordinate Index Map. Unshaded areas indicate lack of corrosion experience.

size, he specifies anode spacing when resistivity measurements indicate that they should be utilized. In addition, he observes installation techniques and may demonstrate, upon request of the foreman, the correct method of bonding across compression couplings, installing anodes, test wires, insulating couplings, operation of a pipe coating "holiday" detector, the approved method of repairing "holidays," etc.

Note that so far only magnesium anode protection has been mentioned. Due to the preponderance of other utility underground structures within the District of Columbia and some of the densely populated suburbs, no cathodic rectifier protection has been applied to the distribution system. However, three small units are installed on sections of one 16-inch transmission line and one will soon be installed to protect the entire feeder main and distribution system for the small rural communities of Vienna and Fairfax, Virginia, consisting of several hundred houses to which gas supply has been extended. In the preliminary planning stage of the Vienna extension, soil resistivity measurements were made and recorded on coordinate maps. This information proved useful in selection of a rectifier ground bed location.

Foremen Train Personnel

The problem of training company personnel within a gang is the foreman's responsibility. In contractor's gangs it is handled by the contractor's foremen in a manner approved by a company inspector assigned to the gang on a full-time basis. Distribution of information to foremen and inspectors pertinent to corrosion control is accomplished by issuing procedures and operating instructions as necessary.

When new instructions are issued, to eliminate

faulty practices that may occur through misunderstanding of instructions, the assistant general foremen and the Corrosion Control Group review the instructions with crew supervisors.

On days when weather does not permit working in the field, the gang supervisors are required to attend group meetings. These meetings are utilized, among other things, to instruct them in the fundamentals of corrosion and its control and to review pertinent procedures and operating instructions.

Present policy is to protect adequately all new and replacement installations and old installations as they are brought to the group's attention through leakage surveys, paving activity, etc.

The testing of corrosion control installations to determine their effectiveness is important. To date, the problems of design, training and the development of suitable operating procedures have occupied a considerable portion of time available. The recent addition to the group of another man, now in training, will provide opportunity for additional field observations and testing, which to date has been too limited for worthwhile discussion here. However, it can be said that, although some highly satisfactory results have been obtained, tests on some lines indicate that protection is below the desired level. This usually occurs in some of the built-up sections of the city where positive isolation from other utility structures, as well as bare portions of the system, is particularly difficult. However, insulating joints are provided on all new and replacement meter installations to eliminate direct connection to the underground water piping through the water heater, furnace, or boiler and the company contemplates expansion of this method of insulation through use of kits to change meter connections to an insulating type at the time of periodic meter change.

In short, the tests made to date indicate that, while correct design and installation are necessary, the importance of an adequate testing program cannot be overemphasized. It is believed that the program should include an initial test soon after completion of the job and periodic checks to prove continued satisfactory performance.

Early in the program, the testing indicated that expanded use of pipe coating "holiday" detectors was essential. The company now owns 14 of these devices and has 10 more on order. With these, it is expected that it will be possible to inspect and repair coating on more than 80 percent of the wrapped pipe that is used for mains and much of that used for services. The value of a good coating was illustrated in the design survey for the proposed rectifier installation mentioned earlier. It was found that approximately 40,000 square feet of pipe surface in this small distribution system and attached 2½ mile feeder main, all of which was "jeeped" at time of installation, can be amply protected by approximately 1.5 amperes.

A complete list of problems and activities of a Corrosion Control Group are too numerous to discuss in one paper of this nature. A few of the more important ones have been covered. In view of the vast differences in conditions between long transmission lines and concentrated distribution networks, it appears that more discussions of the distribution problems are desirable. With the increase in number of distribution companies organizing programs, the experiences of engineers who have been in the game for several years would be invaluable in getting them off to the right start.

DISCUSSION

Question by Ralph E. Kuster, Union Gas Company of Canada, Ltd., Chatham, Ont.:

When cathodically protecting plant in a new subdivision in a corrosive area do you make allowance for the probable increase in customers at a future date? In other words, do you install additional magnesium anodes to take care of extra service piping that will be added from time to time as the subdivision develops?

Reply by J. W. McAmis:

At presentwe do not make specific allowance, as such, for probable increase in customers. In new subdivision jobs houses are usually built "as close together as the law allows" so that no allowance for future growth is necessary. However, we do try to use a safety factor large enough on mains protection to cover all possible services from mains and are considering use of smaller anodes on each future service. This, of course, would reduce the anode requirements on new mains and provide some protection on older unprotected mains.

Question by Robert H. Kerr, Southern California Gas Co., Los Angeles, Cal.:

Do you protect each separate main extension or replacement as an individual insulated cathodic protection unit or do you insulate and protect larger unit areas? If the latter, what are the approximate sizes of the areas?

Reply by J. W. McAmis:

We do both depending on individual job. When connecting to cast iron or bare steel we consider each wrapped steel extension as a separate unit with insulation at the tie-in and anodes on the extension. Wrapped steel extensions from wrapped mains are considered as a unit in determining anodes for protection but may or may not be insulated from existing system at point of tie-in. To minimize the effect of stray electric currents and to facilitate future tests of, and adjustments to, the protection system we install insulating joints at approximately 2000-foot intervals. However, this is not a fixed distance and, depending on conditions at the specific location, it may be considerably greater or less than 200 feet.

Any discussions of this article not published above will appear in the December, 1955 issue.

The Pertechnetate Ion as an Inhibitor Of the Corrosion of Iron and Steel*

By G. H. CARTLEDGE*

Abstract

Theoretical consideration of possible mechanisms to account for the action of inorganic corrosion inhibitors of the XO_4^{n-} type led to the discovery that the pertechnetate ion, TcO_4^-, inhibits the corrosion of iron and carbon steels in aerated water at temperatures from 23 to 250 C, which was the highest temperature investigated. The chemistry and nuclear properties of technetium are such as to make it very useful in studying the inhibitory process. Thus, it has been shown that inhibition may be achieved without precipitating more than radiochemical traces of reaction products on the metal and even this amount is shown to be most probably of secondary origin. Exposures of two years have not been attended by a continuous increase in the amount of precipitated technetium. It was found that even at 250 C 5 ppm of technetium (5×10^{-5} *f* $KTcO_4$) in distilled aerated water effectively inhibited the attack on an SAE 1010 steel. The inhibition depends upon the maintenance of some minimum concentration of dissolved pertechnetate, the amount being dependent upon the nature of the metal and its surface activity. The evidence points to a weak, reversible adsorption of the inhibitor ion as the source of inhibition. The perrhenate ion, ReO_4^-, is very similar to the pertechnetate ion in geometry and charge, yet it was found to have no inhibitory properties under any of several conditions studied. The observations make it clear that inhibition arises from some intra-ionic property and it is tentatively suggested that this is a degree of internal polarity sufficient to induce a short-range electrostatic polarization at the interface, whereby the activation energy for the cathodic part of the corrosion process is increased.

I. Introduction

IN THE STUDY of the mechanism of the corrosion of metals one is immediately involved in the combined action of thermodynamic and kinetic factors, the differentiation of which is not always obvious. Since the over-all thermodynamics is necessarily adverse, otherwise corrosion would not result, it is clear that one must look to kinetic influences if he is to understand the effect of corrosion inhibitors. The present work is a part of a comprehensive study of the comparative behavior of inorganic ions and molecules of the general formula XO_4^{n-} derived from elements of the V-A to VIII groups of the periodic table. This includes vanadium, niobium, chromium, molybdenum, tungsten, technetium, rhenium, ruthenium and osmium in their highest oxides or salts derived therefrom. It was thought that by comparing the effects of these materials upon corrosion with their other properties it might be possible to gain a clearer insight into the specific properties responsible for inhibition of the corrosion of iron and steel.

Among these elements, the use of chromates as inhibitors is well-known. Molybdates and tungstates also have been shown to be inhibitors at concentrations comparable to those required in the use of chromates, these experiments having been done at room temperature[1,2]. Studies on the remaining elements mentioned will be summarized and reported in more detail in a subsequent publication.

The theories of the action of inorganic inhibitors of the type of the chromate ion, $CrO_4^=$, generally center around an oxide film theory, on the one hand, or a theory of chemisorption without reduction of the inhibitor by reaction with the metal, on the other. According to the oxide film theory originally proposed by Faraday in his discussion of passivity and developed by many subsequent researches, the chromate ion acts by precipitating a protective film of mixed iron (III) and chromium (III) oxides, the inhibitor being presumed to repair continuously by such means any flaws that may develop in the protective film.[2,3] It is to be noted that in chromate solutions the electrode potential is raised into the noble region in which dissolved iron is oxidized to the iron (III) state. The existence of organic inhibitors which function without being reduced and without producing large changes in the electrode potential makes it clear that other mechanisms for inhibition must also exist.

Theories based upon the adsorption of an inhibitor, either on specific sites or else over the surface generally, have been developed by a number of workers. Various theories of this type have been discussed by Hackerman and Makrides.[4] Uhlig[5,6] also discussed inhibition by chemisorption of ions, taking into account the electronic configuration of the metal serving as substrate.

In adsorption theories, the origin of the force leading to adsorption and the specific way in which adsorption affects the corrosion rate are two distinct problems and have been variously interpreted. Hackerman and Makrides ascribe the action of organic inhibitors to the formation of a dative bond between the inhibitor and the metal. Uhlig assumes that the inhibitor is chemisorbed, "thereby satisfying surface valence forces of the metal" and setting up a dipole layer such that the potential becomes more noble.

While it may well be that inhibition may result from a number of different causes, it seems clear that such causes cannot arise from either the charge of the ion as a unit or interactions of its oxygen atoms with the surface. Thus, the sulfate and chromate ions have equal charges, similar configurations and not greatly different dimensions. They should therefore act alike, unless some differentiation *within* the ion is assumed. Yet the chromate ion is an inhibitor, whereas the sulfate ion is not. A more striking example of the

★A paper presented at the Eleventh Annual Conference, National Association of Corrosion Engineers, Chicago, Ill., March 7-11, 1955.
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same sort was discovered in the course of the present work, in which it was found that the pertechnetate ion, TcO_4^-, is an excellent inhibitor whereas the perrhenate ion, ReO_4^-, does not inhibit, although the two ions are essentially identical in size and have the same configuration and charge.

Considerations of this sort suggested that since the difference between the chromate and sulfate ions must be sought in an intra-ionic difference, the inhibiting property itself must reside in some specific internal property of the XO_4^{n-} ion or molecule. Such differences conceivably could arise from one or more of the following characteristics:

a) different stable states of valence;

b) different redox potentials;

c) differing activation energies for transitions between valence states;

d) different charge distribution within the ion, as, for example, in the presumption that the sulfate ion is bonded chiefly covalently whereas the bonding between the chromium and oxygen atoms may be distinctly ionic.

These considerations led to the possibility of ascribing the inhibiting properties to a short-range electrostatic polarization of the surface of the substrate under the influence of polarities existing within the inhibitor ion. This idea will be developed more fully after presenting the results of the experiments. It was such reasoning, however, that suggested the possibility that, of all the XO_4 ions and molecules, the pertechnetate ion should most closely resemble the chromate ion in relation to corrosion, since it is derived from a transition metal in the +7 valence state and is a milder oxidizing agent than either the chromate ion or the permanganate ion. The higher central charge would compensate for the somewhat larger size of the pertechnetate ion, as compared with the chromate ion. The very first experiment strikingly demonstrated the correctness of this expectation.

The discovery of the effectiveness of the pertechnetate ion as an inhibitor is very fortunate for the detailed study of inhibition. Technetium, atomic number 43, derives its name from the fact that it was the first of the previously unknown elements to be artificially prepared. This achievement was accomplished in 1937 by Perrier and Segré,[7] who obtained infinitesimal amounts of technetium by bombarding a molybdenum target with neutrons or deuterons. Much larger amounts of the element have been produced by separation from the fission products of nuclear reactors, the yield of technetium as a daughter of Mo^{99} being about 6.2 percent of the U^{235} atoms undergoing fission.

The element occurs in the VII-A family of the periodic system along with manganese and rhenium. Numerous properties of the metal and of its compounds have been described in the literature.[8, 9, 10, 11, 12, 13] The maximum valence of technetium is 7^+, in which state it forms an oxide Tc_2O_7, an acid $HTcO_4$, and such salts as potassium pertechnetate, $KTcO_4$. These compounds differ from the analogously constituted manganese compounds in being more stable with respect to reduction; the pertechnetate ion is colorless, in sharp contrast to the permanganate ion. Technetium also forms a dioxide, TcO_2, by reduction of the pertechnetates in acid solution. The thermodynamic relationships among the different valence states are summarized in the following diagram, which shows the molar electrode potentials for transitions between the different valence states in acid solutions.[12a]

$$Tc^- \xrightarrow{(-0.5)} Tc \xrightarrow{+0.272} TcO_2 \xrightarrow{+0.8} TcO_3 \xrightarrow{+0.7} TcO_4^-$$

$$\underbrace{TcO_2 \to TcO_4^-}_{+0.738^*} \qquad \underbrace{Tc \to TcO_4^-}_{+0.472}$$

* European convention for signs.

TABLE 1—Molar Extinction Coefficient of Aqueous Potassium Pertechnetate

SAMPLE	2440 Å	2875 Å	Ratio
S-3	6150	2320	2.65
S-4	6280	2395	2.62
Average	6220	2360	2.64

The pertechnetate ion has a strong absorption in the ultraviolet region of the spectrum which is very useful for quantitative determination of the ion in the absence of interfering substances. Thus, in using a 1-cm absorption cell in a Model DU Beckman Spectrophotometer, quantities of 2 to 15 ppm of metal give convenient optical densities; with a longer cell even lower quantities may be determined. The potassium pertechnetate used in this investigation consisted of solutions accurately prepared by weighing very pure crystalline salt. This material was separated from fission products and the potassium salt had been recrystallized until it was believed to be free from all significant impurities.* Spectrographic analysis revealed the presence of no impurities other than spectrographic traces of calcium, magnesium and silicon. No rhenium was indicated within the limit of detection of approximately 10 ppm.

The absorption spectrum of three solutions prepared from the two batches of crystals was redetermined. The solutions were $1.05_6 \times 10^{-4}$, $2.11_2 \times 10^{-4}$, and $1.58_5 \times 10^{-4}$ f respectively. The wave-length scale was calibrated against a mercury-vapor spectrum. Table 1 gives the molar extinction coefficients, ϵ, found at the two maxima of analytical interest. The coefficient is defined by the equation, $\log I_0/I = \epsilon\ c\ l$, in which c is in moles per l. and l is in cm.

Measurement of a particular solution at intervals showed the solution to be stable even after months of preservation.

The technetium isotope of atomic mass 99 is radioactive but has a long half-life of approximately 2.2×10^5 years. It emits a 0.3 mev beta radiation. The dilute solutions containing inhibitor concentrations of the potassium salt may, therefore, be handled without special precautions other than the avoidance of radiochemical contamination. The specific activity of about 16 microcuries per mg of metal corresponds to

* The author is indebted to G. W. Parker and W. J. Martin of the Hot Laboratory Research Group of this Division for supplying this pure salt.

6×10^5 disintegrations per sec. per mg., so that convenient counting rates are obtained from the minute amounts that normally deposit on inhibited specimens. In the present experiments, quantitative determination was made by using the absorption spectrum for standardizing solutions and beta activity for determining the deposit on metallic specimens. For the latter purpose, a calibration curve was prepared by evaporation of aliquots of standard solutions upon stainless steel shelves that fitted directly in the counter.

II. Test Materials and Procedures

1. Ferrous Materials. The following is a list of the ferrous materials used in the course of the inhibition tests.

Sample No. 1 was electrolytic iron of approximately 10 mil thickness prepared in the Metallurgy Division of the University of Vermont and obtained through the courtesy of the Metallurgy Division of this laboratory. This specimen was supplied with the following analysis: C 0.01, Mn 0.003, P 0.011, Si 0.020, S 0.034, Ni absent, Cu absent, Cr absent, Fe by difference 99.922 percent.

Sample No. 102, SAE 1010, half-inch mild steel strap, having the following analysis: C 0.097, Ni 0.066, Mn 0.51, Cr < 0.01 percent.

Sample No. 103, cast iron, not analyzed.

Sample No. 104, iron wire 16 mil diameter, supplied by Jones and Laughlin Steel Company through the courtesy of Dr. H. F. Beeghly. This sample had the following analysis: C 0.32, Mn 0.79, P 0.015, S 0.036, Si 0.22 percent.

Sample No. 300, used in a few experiments, was a niobium-stabilized stainless steel, Type 347, 10-mil annealed sheet, having the following partial analysis: C 0.05, Cr 18.10, Ni 9.75, Mn 0.71, Si 0.59, Nb 0.57 percent.

2. Surface Preparation. In most of the experiments the surfaces were lightly polished by hand with abrasive papers, the polishing being generally finished with 2/0 emery. In some cases the specimens were electropolished, though this procedure was not entirely satisfactory when applied to carbon steels. The polishing bath consisted of 85 percent phosphoric acid to which was added 5 grams of chromic acid per 100 ml. For stainless steel the bath was phosphoric acid 60, sulfuric acid 20, water 20 parts by volume. The anodic current density was held at about 0.5 amp/cm^2, and polishing was continued for 2 to 5 minutes at 65 C. All specimens were degreased in acetone before use.

3. Test Procedures. Whereas a few experiments were made at laboratory temperature, the majority of the tests for inhibition were carried out at higher temperatures. Unless other conditions are specified, it may be assumed that 1 x 2 cm test specimens were immersed in 10 ml of solution in a container made by closing the end of the outer part of a water-cooled 19/38 standard-taper joint so as to make a test tube 175 mm long. The inner part of the joint was drawn down to a 6 mm tube and bent at a 90 degree angle. Four of these tubes were inserted into a 5-necked 500 ml flask having a reflux condenser through the center opening. The flask was heated by a glass-col mantle. In the usual procedure the water in the flask was kept just at the boiling point during the daytime and at room temperature at night. At all times the solutions were open to the air through the short condenser.

When experiments were conducted at 250 C, the specimens were held in a Teflon block which rested on the bottom of a platinum-lined bomb. Ten ml of solution was placed in the bomb, which had a total volume of approximately 50 ml, and the bomb was then sealed at atmospheric pressure. The bombs were heated in a fused-salt constant-temperature bath.

In those experiments in which technetium was used at inhibiting concentrations, qualitative evaluation was obtained by visual observation, since it was noted that incipient corrosion could be detected by turbidity or discoloration long before significant changes in weight occurred. Loss in weight of corroding specimens was approximately determined after brushing off loose rust under running water and rubbing the specimen on a paper towel. The technetium consumed on inhibited specimens was determined by counting the specimen after it had been rinsed thoroughly with water, then with acetone and dried on a paper towel.

4. Autoradiograms. In a number of experiments location of technetium which had been deposited on a specimen was determined by autoradiography. For this purpose, high-contrast lantern slide plates were used with due precaution to avoid development of a latent image by pressure. Exposure times from 1 to 40 hours were used, depending upon the amount and distribution of the activity on the specimen. Comparison of the autoradiogram with the original specimen was made by superimposing the photographic plate over the specimen under a low-power binocular miscroscope. In case a heavy silver deposit was present, it was impossible to see the specimen through the photographic deposit. It was found that microscopic observation could be greatly facilitated in these instances by transforming the silver into silver iodide on the developed and fixed plate. This was accomplished by immersing the plate in an aqueous solution containing potassium ferricyanide, potassium iodide and iodine. After conversion of the silver, the plate was again washed in photographic hypo and finally in water. It was then usually possible to see the underlying metal through the greenish-yellow silver iodide film.

III. Demonstration of Inhibitive Properties

In this investigation there has been no attempt to make a thoroughgoing determination of corrosion rates under conditions having reference to particular applications. Since the primary purpose was a study of the chemistry involved in corrosion and its inhibition, after the inhibitor properties were demonstrated the work was devoted to attempts to elucidate the details of the inhibiting action. This section will de-

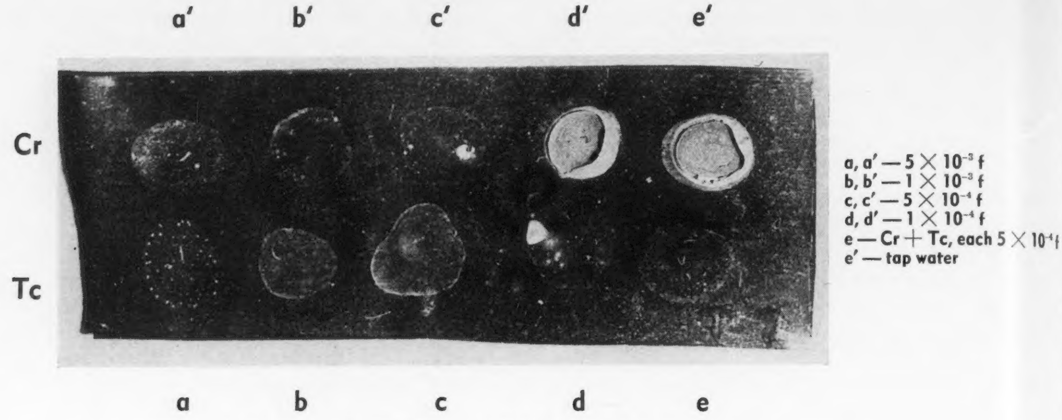


Figure 1—Spotting tests with $KTcO_4$ and K_2CrO_4 on electrolytic iron.

scribe the experiments which demonstrated that the pertechnetate ion does, in fact, act as an inhibitor for the corrosion of iron and mild steel in areated water over a considerable range of temperatures.

1. Preliminary Experiments. As a matter of historical interest, the first experiment, which was done on November 6, 1952, successfully demonstrated the inhibiting character of potassium pertechnetate. This experiment was made by cleaning a piece of electrolytic iron (sample No. 1) and placing upon it four drops of different solutions; one drop was tap water; a second was 0.01 *f* $KTcO_4$; the third was a drop of the same pertechnetate solution plus one drop of tap water; and the fourth was 0.003 *f* K_2CrO_4. The metal was covered with a large funnel and allowed to stand at room temperature until the drops evaporated. The pertechnetate and chromate spots remained free of rust, while the spot covered with tap water was heavily rusted. A photograph of a similar spotting test at room temperature is shown in Figure 1. From this crude test it was apparent that the pertechnetate solution was effective at somewhat lower concentrations than were required for chromate inhibition under these conditions. The small spots and smudges seen on most of the spots were evaporated salt; c' and d showed small areas of attack, while d' and e' were heavily rusted.

2. Inhibition at 100 C. The major portion of the experiments have been conducted according to the procedure described in Section II.3, wherein the solution was kept near 100 C during the work days and cooled overnight, with constant exposure to the atmosphere. It was found that under these experimental conditions a convenient graphical representation of the corrosion rate of uninhibited specimens could be obtained empirically by counting 16 hours at room temperature as equivalent to one hour at 100 C. The results obtained during the first few weeks of one set of experiments are presented in Figure 2. In these experiments, portions of mild steel (sample No. 102) 1 x 2 cm in size were polished with emery paper, degreased and then exposed to 10 ml portions of the appropriate solution.

In experiment T-28 the solvent was distilled water;

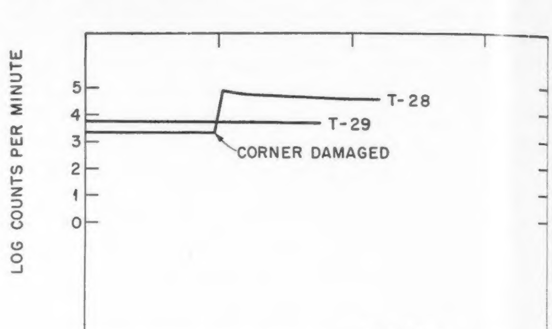


Figure 2—Weight changes and counts per minute.

10 ppm of chloride ion as potassium chloride was present in T-29. Two specimens were run as controls and two in 5×10^{-4} *f* $KTcO_4$ (50 ppm Tc). As may be seen from the graph, the controls corroded rapidly, whereas the two specimens exposed to technetium suffered no weight change within the accuracy of the analytical balance ($\pm$ 0.2 mg).

It will be noted from the upper portion of Figure 2 that the beta activity remained essentially constant after the first two hours at 100 C until specimen T-28 was accidentally dropped in returning it to its tube. This caused its activity to rise to a higher level, but without loss of inhibition. Both specimens exposed in the pertechnetate solution remained bright and the solutions remained clear and colorless. The control specimens in this experiment were discarded at the end of approximately three months, at which time their weights had decreased by 21 mg and 46 mg re-

spectively, the greater loss being in the solution containing chloride ion.

The inhibited specimens were left in their respective solutions at laboratory temperature and were periodically weighed and counted. Twenty three months after the beginning of the experiment there was no visible change in either the specimens or the clear solution and the weights were unchanged.* The beta activity on sample T-29 fluctuated around a value corresponding to 3.5 ($\pm$ 0.1) x 10^{-5} mg/cm^2 of technetium, the number in parentheses being the average deviation from the mean of 11 measurements between March 1953 and December 1954. Similar results were obtained on other specimens subjected to long observation. It is to be noted that 3.5 x 10^{-5} mg/cm^2 corresponds to only 2.1 x 10^{14} atoms of technetium per cm^2 of geometrical area.

A series of experiments was made with the same steel (sample No. 102) under the usual conditions (100 C during the day and 23 degrees overnight) to determine the minimum amount of technetium required for inhibition. After the tests had run long enough to be certain of the results (days or weeks) certain specimens were continued at room temperature for longer periods. There was a rather sharp break between essentially complete inhibition and rapid corrosion. In only one instance has it been observed that slight rust formation occurred initially and then ceased. Table 2 shows the results of a series of experiments that fixed the inhibiting minimum at about 5 ppm when using this particular metal and the specified experimental conditions. At 3 ppm the corrosion was about as rapid as in water alone and the technetium count on the metal was very high.

The amount of technetium required for inhibition varied, however, with the nature of the ferrous metal. A few experiments were done with steel wire (sample No. 104) having a carbon content of 0.32 percent. This specimen was not always inhibited in 5-10 ppm Tc either at 23 C or at 100 C, though it was completely inhibited at both temperatures at 15 ppm Tc. In like manner cast iron was found to require still higher concentrations of technetium. When a milled specimen was exposed at 100 C to 10 ppm Tc, reduction to a dark coating was apparent within twenty minutes and a beta count after 2.6 hours showed that the amount of technetium left in solution was below the inhibitive limit previously found for mild steel. The specimen subsequently corroded. A second milled specimen of the same cast iron was exposed to 50 ppm Tc at 100 C. This specimen also precipitated a large amount of the technetium on its surface and after three days showed a slight degree of corrosion. In other experiments the cast iron was emery polished. It was then exposed to 50 ppm Tc in distilled water at 100 C. After one week the solution was still water-clear and the specimen was covered by a bronze film with interference colors here and there. The beta count showed approximately 0.05 mg of technetium to have been deposited on the specimen from the total of 0.50 mg initially present. This experiment was duplicated by using 5 x 10^{-4} f K_2CrO_4 with an identical metal specimen. At the end of one week the specimen had rusted at the corners where it made contact with the test tube. A brassy film covered the entire surface elsewhere and the chromate had been entirely reduced and removed from solution.

In further tests with the same emery-polished cast iron the specimen was first immersed in 1 x 10^{-3} f K_2CrO_4 for approximately one day, part of the time at 100 C, and was then transferred to a pertechnetate solution of 50 ppm Tc. It was thought that pretreatment in the chromate solution might suffice to oxidize the more active areas and so diminish the amount of technetium activity deposited on the metal. This was found to be the case. Whereas about 10 percent of the technetium was removed from solution by the untreated cast iron, pretreatment in potassium chromate reduced this loss to approximately 1.1 percent and 1.6 percent of the technetium present in two experiments. During seven months of observations the specimen remained unattacked except for a small area of brown smudge that formed at the very beginning. Here again the beta counts fluctuated up and down over a range of about 12 percent of the total count.

3. Experiments at 250 C. Several experiments were carried out at 250 C merely to determine whether inhibition persists under these conditions. The platinum-lined bomb described in Section II.3 was used. Specimens of carbon steel (sample No. 102) 1 cm square were emery polished, degreased and mounted by sticking one corner in a small slit in a Teflon block. This block rested on the bottom of the bomb and the specimen was covered with 10 ml of solution. This left approximately 40 ml of air space when the bomb was closed.* In tests lasting 92 hours the control specimen initially weighing 0.2828 g lost 9.0 mg after incomplete descaling. The water was filled with loose mud. A second specimen was heated simultaneously in 1 x 10^{-3} f $KTcO_4$ (100 ppm). The solution in this bomb remained water-clear and there was no sediment. The specimen weighed 0.2870 g initially and the same at the end of the experiment. The beta count showed that approximately 3.5 x 10^{-3} mg of technetium had been removed from the solution, which contained 1.0 mg initially.

A similar experiment was done to determine whether still lower concentrations of technetium are effective also at 250 C. Specimens of the same carbon steel (sample No. 102) weighing approximately 0.3 g were exposed in the platinum-lined bombs to distilled water containing 5 and 10 ppm Tc, respectively.

TABLE 2—Inhibitory Effect at Different Concentrations

Tc (ppm)	$KTcO_4$ Concentration (f)	Observations
1	1 x 10^{-5}	Spotting within 15 min.; rusted overnight
3	3 x 10^{-5}	Spotting within 15 min.; rust evident in 2 hours
5	5 x 10^{-5}	Complete inhibition; 61 weeks' observation
7	7 x 10^{-5}	Complete inhibition; 61 weeks' observation
10	1 x 10^{-4}	Complete inhibition; 61 weeks' observation
15	1.5 x 10^{-4}	Complete inhibition; 61 weeks' observation
25	2.5 x 10^{-4}	Complete inhibition; 61 weeks' observation
36	3.6 x 10^{-4}	Complete inhibition; 61 weeks' observation
50	5.0 x 10^{-4}	Complete inhibition; 101 weeks' observation

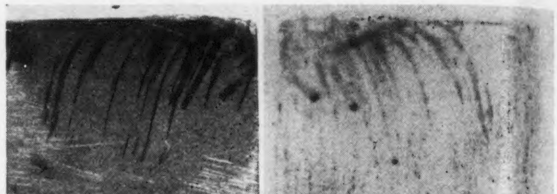
*After 31 months this is still true.

The bombs were kept at 250 C for 116 hours. Both solutions remained water-clear and the weights of the specimens remained unchanged. Beta counting showed that in each case approximately 1.8×10^{-3} mg of technetium was precipitated on the specimen. These experiments made it evident that, for the emeried mild steel employed, inhibition in the aerated solution at 250 C required no more technetium than is necessary at the lower temperatures.

4. Non-Persistence of Inhibition. The inhibition of corrosion induced by the pertechnetate ion was found not to persist when the iron specimen was removed from the inhibiting solution. This was found to be true regardless of the amount of insoluble technetium retained on the specimen after thorough washing. That the inhibition necessitates the presence of a certain minimum concentration of dissolved pertechnetate was demonstrated also in the following experiments.

Specimens of SAE 1010 (sample No. 102) were inhibited in solutions containing 60 ppm of technetium in distilled water at 100 C. The solutions were then diluted in stages to determine whether the surface condition produced at the higher concentration would remain protective after dilution. Dilution to 30 ppm gave continuing inhibition. The specimen diluted to 10 ppm remained bright except for some spotting at the contact of the corners of the specimen with the glass tube. Two specimens diluted to 3 ppm began to rust actively within two hours after dilution. In another experiment, a specimen exposed to 16 ppm remained inhibited while a similar specimen diluted from 16 to 8 ppm slowly developed a slightly mottled appearance and other specimens diluted from 16 to 3 ppm began corroding within 15 minutes after dilution at 100 C. A third series of dilution tests was made with the steel wire (sample No. 104) with similar results. These experiments make clear the dependence of the inhibiting process upon the presence of an adequate concentration of dissolved pertechnetate. In no case has a specimen previously inhibited in the pertechnetate failed to corrode when removed from the solution and exposed to distilled water.

5. The Effect of Acidity and Electrolytes. The pertechnetate ion is rapidly reduced by active metals in sufficiently acidic solution,[13] the product being technetium dioxide, TcO_2. No extensive experiments have been made to determine the precise range of acidity within which inhibition may be achieved. It has been found, however, that with the carbon steel (sample No. 102) used chiefly in these experiments, inhibition is effective in distilled water within the pH range 5.5 to 9.0 at least. The experiments were done by making a 10^{-4} *f* solution of sulfuric acid and adjusting the pH by addition of very dilute sodium hydroxide. Under these conditions the amount of technetium precipitated on the surface was apparently enhanced by the presence of the electrolyte, though the specimens were well inhibited during the brief duration of the experiments. The presence of chlorides at



A B

Figure 3—Scratched stainless steel, A, and its autoradiogram after exposure to potassium pertechnetate.

sufficiently low concentrations does not prevent inhibition but requires an increase in the quantity of technetium. It was repeatedly found that 50 ppm of technetium inhibited the corrosion of mild steel at 100 C when 10 ppm of chloride ion was present as potassium chloride. The same amount of technetium failed to inhibit when 25 ppm of chloride ion was present.

IV. General Features of the Inhibition

The inhibiting power of the pertechnetate ion having been established, the radioactivity of the element was utilized to determine a number of features of the inhibitory process. The details of this portion of the investigations will be presented in other papers, but certain of the results may be briefly outlined.

In the inhibition experiments some of the inhibitor was invariably left on the thoroughly washed metal specimen. The amount, as determined by the beta counts, varied over a wide range according to the surface activity of the metal. Thus it was found to be concentrated in scratches or flaws in the metal. In specimen T-29, for example, during the first six minutes of exposure of the metal to the inhibiting solution at 100 C a dark bluish area 0.06×0.1 cm. developed around a defect in the metal. This represented only 0.25 percent of the geometrical surface area on the affected side but accounted for roughly 50 percent of the beta counts from that side. The spot remained unchanged during the remaining two years of the experiment, at the end of which time it still carried 50 percent of the activity.

In like manner, a piece of stainless steel was scratched with a file and then exposed to a pertechnetate solution in 0.1 N sulfuric acid at 100 C until it had acquired 15,000 counts/min./cm^2. Figure 3 shows the specimen A and its autoradiogram B. It is clear that the technetium deposited selectively in the scratches.

The precipitation of insoluble technetium does not, of itself, lead to inhibition, however. If a solution is used which is insufficiently concentrated to inhibit corrosion, reduction of the pertechnetate ion proceeds rapidly.

Neither was any limiting amount of deposit found to be essential for inhibition. Experiments carried out specifically to test this point achieved inhibition under very corrosive conditions with deposition of only about 5×10^{-10} g, or 3×10^{12} atoms of tech-

* The author is indebted to J. S. Gill for the loan of the bombs and fused-salt bath used in all the experiments conducted at 250 C.

netium per cm^2 of geometrical area. With the assumption of any likely roughness factor, this would represent only a very small fraction of one percent of a monatomic layer even if it were uniformly distributed, which almost surely is not the case. This amount of technetium activity is to be compared with the 5.5×10^{15} atoms of chromium per cm^2 reported by Brasher and Stove[14] and 5.2×10^{15} atoms/cm^2 similarly reported by Powers and Hackerman[15] for the treatment of carbon steel in chromate solutions at 25 C.

It has been found that the pertechnetate ion is reduced, most probably to the dioxide TcO_2 wherever iron is corroding, as at an attackable anode. Since the pertechnetate ion is just able, thermodynamically, to oxidize ferrous ions to iron (III) hydroxide at a sufficiently high pH, it is believed that the observed deposit is a secondary product of local attack consisting of a mixture of iron and technetium oxides. The formation of this deposit may be greatly reduced by cleaning up the surface chemically or electrochemically before exposure to the pertechnetate, though such pretreatment does not prevent corrosion in the absence of inhibitor.

The experiments also have demonstrated that the inhibitory process involves a labile state which is most probably to be described as a competitive adsorption of the inhibitor particle. Current events, rather than history, determine whether corrosion is arrested. The "current events" are not such, however, as to cause a continuing increase in the amount of precipitated technetium, as shown by the beta activity of specimens observed for up to two years. Not only so, but it was found that the presence of other ions, including the sulfate ion, in sufficient concentration weakens the inhibiting power of the pertechnetate ion and similarly affects other properties of the metal-solution system. This conclusion is in agreement with the data of Hackerman and Powers,[16] who showed that there is a similar competition between chromate and sulfate ions adsorbed on chromium.

V. The Behavior of Other XO_4^{n-} Particles

Of special importance for inhibitor theory was the observation that the perrhenate ion, ReO_4^-, failed to inhibit under any conditions investigated. A radioactive salt prepared by neutron bombardment was used in a few experiments to insure that the difference in the action of the two otherwise very similar ions was not due to the radioactivity of technetium. This result reinforces the conclusion stated previously that the inhibition of the XO_4^{n-} ions or molecules that are effective must derive from some property having its source *within* the particle, rather than in effects arising from image charges due to the ion as a unit or from interactions of the tetrahedral oxygen atoms of the XO_4 particle with the substrate.

Study of the other XO_4^{n-} ions and molecules referred to in the introduction showed that neither vanadate nor molybdate maintained inhibition at 100 C under the conditions used in these experiments. Both niobate and tungstate at pH's above nine proved effective but only when present at much higher concentrations than were necessary with the pertechnetate. Ruthenium (VIII) oxide, RuO_4, in aqueous solution was found to be immediately reduced by the carbon steel (sample No. 102) at 100 C and gave extremely fast corrosion.* On the contrary, it was found that osmium (VIII) oxide, OsO_4, in a 1 percent solution (*ca* 0.04 *f*) passivated iron and steel as does concentrated nitric acid. A sensitive state was produced which resulted in slow formation of a visible film, especially at 100 C. The film was easily ruptured, whereupon pits formed slowly in the poorly conducting solution, or rapidly if a little sodium sulfate was present. Most of the surface then remained covered with a bluish or brassy cathodic film.

The hypothesis which initially led to this study involved the search for some intra-ionic property to which the inhibition might be ascribed. As was pointed out earlier, the difference between the pertechnetate and perrhenate ions with respect to inhibition required this difference to be sought in the internal electrical character of the ions. Their net charges are the same, they are both tetrahedral and the ions are of almost identical size. The XO_4^{n-} particles having very high redox potentials (MnO_4^-, RuO_4) are rapidly reduced and the reaction products do not form protective films under the conditions of the present work. The ability to oxidize ferrous ions is, therefore, not enough; it is, in fact, disadvantageous if the unreduced particle is the effective inhibitor.

If, as the evidence seems to indicate, the unreduced particle is really the inhibitor and is loosely, rather than irreversibly, adsorbed then it may be that its action depends upon an internal charge distribution which permits it to concentrate negative charge under its site of adsorption, without exerting a sufficient pull for actual electron transfer to occur. The redox potential should not, therefore, be too high, or else there should be a high activation energy for the redox reaction. The general results of the investigation support such a tentative suggestion. Table 3 gives the redox potentials calculated for various XO_4's assumed to be 10^{-3} *f* in a solution of pH 6, with reduction to either XO_2 (c) or other product, as indicated.[17]

The very noble potentials of the MnO_4^- and RuO_4 couples correspond to the immediate reduction of these substances by carbon steel at 100 C. The best inhibiting properties occurred with TcO_4^-, whereas both $CrO_4^=$ and OsO_4 passivated the steel with simultaneous reduction of some of the passivating material.

TABLE 3—Calculated Redox Potentials of Various XO_4^{n-} Couples

V	VI	VII	VIII
V 0.23*	Cr 0.61*	Mn 1.16	Fe ......
Nb	Mo ca 0.0*	Tc 0.20	Ru ca 0.9?
Ta	W	Re —0.03* —0.17	Os ca 0.6

pH = 6; $XO_4 = 10^{-3}$ f.
Reduction to XO_2 unless noted.
*V_2O_4; $Cr(OH)_3$; Mo_3O_8; ReO_3.

* The experiments with vanadates, molybdates, tungstates and ruthenium (VIII) oxide were carried out in collaboration with Dr. Ruth P. Yaffe.

VI. Summary

The inhibition experiments themselves may be summarized as follows: The corrosion of electrolytic iron, mild steel and cast iron in aerated water has been shown to be inhibited by potassium pertechnetate at very low concentrations. In a few experiments the temperature was 250 C, and a 5×10^{-5} *f* solution (5 ppm Tc) was effective at this temperature with an SAE 1010 steel for a test period of 116 hours. Both the quantity of inhibitor required and the loss due to reduction were found to be highly dependent upon the composition and surface activity of the ferrous material. The inhibition was shown to depend upon the maintenance of an adequate concentration of dissolved pertechnetate in contact with the metal and was lost when the solution was diluted below this limit. Also, there was no inhibition when the solution was sufficiently acidic. At 100 C the pertechnetate ion inhibited at lower concentrations than were required by the chromate ion. In experiments extending over a period of two years there has been no evidence of corrosion nor of continuous reduction of the inhibitor.

Experiments with other XO_4^{n-} ions or molecules have been briefly presented, together with some suggestions regarding the bearing of the results on the theory of inhibitor action.

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DISCUSSIONS

Remarks by Norman Hackerman, University of Texas, Austin:

There is a question to the effect that there is a dependence of minimum TcO_4^- concentration on the carbon content of the steel. Do you feel that it has anything to do with a possible increase in number and area of anodes as carbon increases?

Reply by G. H. Cartledge:

I do not believe enough information is at hand to discuss the relation between carbon content and inhibiting concentration. This is a point which I hope someone will explore more fully. Dr. Hackerman's suggestion is very likely to the point, but I do not feel that it would be justifiable to go further into the subject in the present paper.

Any discussions of this article not published above will appear in the December, 1955 issue.

Design and Application of Corrosion Current Measuring Instruments★

By DONALD L. HAM*

Abstracts

The three principal kinds of instruments used to measure currents associated with corrosion are described and their circuit diagrams illustrated. Considerations involved in selecting the correct instruments for several kinds of current measuring problems are reviewed and the capacities and limitation of the applicable instruments evaluated. Examples of typical uses are given.

THE destructive forces of corrosion on underground structures are well known to many. There are many papers providing information on the detection and correction of corrosion situations. Most corrosion investigations require that data be accumulated by the use of instruments and measurements of the various parameters of the circuit. It is the purpose of this article to offer information to corrosion engineers regarding instruments available for this work. It is also the purpose of this paper to give design information so instruments may be applied effectively to the problems of corrosion investigations.

The various factors governing the design of instruments are presented for a twofold purpose. First of all, they will enable the corrosion engineers to apply the instruments properly and understand their limitations. Secondly, they will enable corrosion engineers to suggest new instrumentation techniques to manufacturers.

Most companies making corrosion testing instruments are willing to cooperate with corrosion engineering people in the development of new techniques and new instrumentation wherever possible. Some of the most useful instruments developed in this field have been the result of such cooperative efforts.

Practically all DC instruments used in corrosion measurements are the D'Arsonval type. The DC D'Arsonval instrument basically is a current sensitive device. It may be arranged to measure either current or voltage. This is purely a matter of the circuit chosen. The mathematics underlying this type of instrument show that for a given spring constant, the instrument will have a resulting power sensitivity which is independent of the number of turns on the moving coil or the resistance of the moving coil, provided the physical dimensions of the instrument remain the same. Instruments having higher sensitivity, that is, lower power consumption are characterized by weaker spring torque and consequently, lower torque-weight ratio. Since the torque-weight ratio is a measure of the instrument's ruggedness, it can be seen easily that the higher sensitivity instruments are not particularly rugged. Conversely, the low sensitivity instruments requiring higher power also withstand rough handling better.

Classification Into Three Groups

As an example of this relationship between ruggedness and power sensitivity, instruments may be classified in three general groups. The first would be those called super-sensitive instruments having power sensitivity in the region of 0.1 to 1.0 microwatt. These are delicate and must be handled carefully when used. Furthermore, during transportation they must be carefully protected from mechanical shocks. This usually is done by mounting the instrument in a container lined with sponge rubber.

The second group of instruments is what may be termed sensitive field instruments having power sensitivities in the order of 10.0 microwatts. These instruments also must be handled with reasonable care during field use and must, furthermore, be protected from shocks during transportation by shock absorbing sponge rubber lining of the containers in which they are transported.

The third group is classed as field instruments for rugged service and take approximately 100.0 microwatts of power in the basic range. These instruments can be handled quite roughly and need no particular protection during transportation, as long as they are not badly abused or severely shocked mechanically. The power sensitivities that are mentioned herein, are those for the basic first range of the instrument, that is the lowest range. As an example, a voltmeter having ranges of .005/.02/.1/.5/2/5/20/50/100 volts at 10,000 ohms per volt, may take one-half a microwatt on its first range of .005 volt. The second range of .02 volt takes four times as much power, or two microwatts. The power consumption increases with voltage and on the 100 volt range the instrument is taking 10,000 microwatts. Since the delicacy of the instrument is determined by the power sensitivity of the lowest range, it is reasonable to say that in buying an instrument or selecting one for a particular measurement, the maximum amount of power that may be drawn from the circuit under measurement should be used in the first range whenever possible. This will result in the instrument selected being as rugged as possible. If this guide is followed, better and more economical service will result from any instrument.

Use of Special Circuits

In addition to the basic instruments described, special circuits may be used to increase effective sensi-

★ Submitted for publication December 27, 1954.
* Sensitive Research Instrument Corp., Mount Vernon, N. Y.

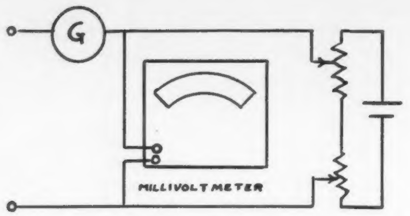


Figure 1—Potentiometer-voltmeter.

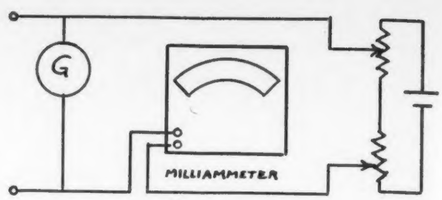


Figure 2—Zero resistance milliammeter.

tivity of the various instruments without causing excessive mechanical delicacy. One of these is the potentiometer voltmeter. This instrument, whose schematic diagram is given in Figure 1, uses a rugged voltmeter or millivoltmeter to give the actual indication, but really depends on a galvanometer for its high sensitivity. In this way, the deflection power for the main instrument is obtained from an internal power source whereas the sensitivity for the instrument is obtained from a galvanometer whose accuracy need not be high. Although this instrument is well suited to field service, there limitations are imposed by the need for manipulation of controls to get balance.

Another special circuit instrument is the zero-resistance current meter. The schematic diagram of the zero-resistance current meter is given in Figure 2. Here again the deflecting power of the main instrument is obtained from internal batteries and the ultimate sensitivity of the instrument is obtained from a galvanometer. Examples given later will illustrate the use and limitations of these types of instruments.

Ideal conditions of voltage measurements would have the instrument impedance so high that it offers no loading on the circuit being measured. Likewise the ideal condition of current measurement is to have a zero-resistance current meter which offers neither loading nor inserted impedance into the circuit. A further idealized condition would be to have the instrument completely undamageable under field service conditions. In some practical applications, these conditions can be approached but in many others practical compromises must be made.

In order to illustrate the use of basic instrument power consumption as a criterion for the selection of measuring equipment, some hypothetical situations are given as examples. Two preliminary assumptions are made in these examples:

First, that the instrument chosen should be in the most rugged classification in order that maximum economy of measurement time and instrument maintenance be effected: and

Second, that the error due to loading of the circuit being measured be fixed at 1 percent in order to make the various situations comparable.

Example 1. (See Figure 3.) Suppose it is desired to measure the voltage drop caused by a current flowing in a cable sheath section whose resistance is known to be 0.01 ohm. The current is expected to be about 1 ampere, giving a drop of .01 volt. To a very close approximation, the cable section could be replaced by an equivalent circuit consisting of a 0.01 volt generator in series with 0.01 ohm. In order to limit the loading error to 1 percent, the instrument resistance must be greater than .01 x 100 or 1 ohm. The instrument power represented by .01 volt across a 1 ohm resistance is $\frac{E^2}{R} = .0001$ watt or 100 microwatts. This places the instrument in the rugged field service class.

Example 2. (See Figure 4.) Assume that a structure-to-structure potential of 0.1 volt is to be measured. The resistance of the circuit as a voltage source is 1000 ohms. To limit the loading error of the voltmeter to 1 percent its resistance must be greater than 100 times the 1000 ohms source resistance, or 100,000 ohms. The power available to the instrument is then $E^2/R = .0000001$ watt or 0.1 microwatt. This measurement, then, requires the most sensitive class of instrument; namely, a 1 million ohms per volt voltmeter, having a 0.1 volt, 100,000 ohm range.

Example 3. (See Figure 5.) Suppose that the source resistance in Example 2 were 10,000 ohms. The voltmeter required then would be one order of magnitude more power sensitive or 0.01 microwatt. Since the ultimate sensitivity of double-pivoted portable instruments is about .05 microwatt, this measurement would be impossible to make with a maximum loading error of 1 percent, using conventional instruments. The solution to this measurement problem would be the use of a potentiometer voltmeter such as the one whose diagram is shown in Figure 1. It is a complete package containing battery, millivolt-voltmeter, galvanometer and control rheostats. The instrument is capable of making measurements which, at balance of the galvanometer, take no current from the circuit under measurement. Thus, using the potentiometer voltmeter, the measurement of 0.1 volt can be made in a circuit having an internal resistance of 10,000 ohms with a loading error of considerably less than 1 percent, a measurement which is not possible with even the most sensitive conventional voltmeters.

Example 4. (See Figure 6.) The current flowing in a structure-to-structure bond is to be measured. The resistance of the bond is very low compared to the 1-ohm source resistance of the circuit and the internal voltage causing the current is 1.0 volt. In order that the error due to the insertion of an instrument into the circuit be kept to within 1 percent, the instrument resistance must be kept to within 1/100 of the total circuit resistance. Thus, the instrument resistance must be kept less than 0.01 ohm. The current to be measured is about 1 ampere and the power

taken by the instrument is $I^2R = .01$ watt or 10,000 microwatts. This could be one of the higher ranges of a rugged instrument having a base range requiring 100 microwatts.

Example 5. (See Figure 7.) Suppose it is desired to insert a current measuring instrument into the circuit of a structure-to-structure bond. The combined resistance of the bond and source resistance is .3 ohm and the emf causing the current is .1 volt, resulting in a current of .333 ampere. In order to limit the error caused by the insertion of the instrument into the circuit to 1 percent, the instrument resistance must be kept below 1/100 of the total circuit resistance. The maximum allowable instrument resistance is 1/100 of .3 ohm or .003 ohm. The power consumption of the instrument is I^2R or .000333 watts. This is 333 microwatts, which indicates that the instrument can be quite rugged. Unfortunately there is a further limitation on the range of this type of instrument. The instrument in this example requires a voltage sensitivity of $E = IR = .001$ volt, which is the minimum useable full scale voltage attainable with the D'Arsonval type of instrument. Thus, although the power available would classify this instrument as one for rugged field service, it happens to fall at the threshold of millivolt sensitivity of delicate type instruments. An alternative solution for this problem would be the use of a zero resistance milliammeter. This instrument is of the rugged field service class but is capable of measuring currents in very low resistance circuits with a negligible volt drop or insertion loss. The circuit diagram of this instrument is shown in Figure 2.

Advantages of Circuits Explained

It has been shown in Examples 3 and 5 that under some conditions the inherent limitations of the straightforward type of voltmeter and ammeter restrict their use. Advantage is gained by using either the potentiometer voltmeter circuit or the zero resistance milliammeter circuit to overcome these limitations. The disadvantage of the potentiometer voltmeter or the zero resistance meter is that manual manipulation is required to obtain a galvanometer balance. If the quantities being measured are varying rapidly, it may be that the variations cannot be followed by manual adjustment of the controls. In this case, these instruments are not the proper solution to the problem. Sometimes it is advantageous to resort to the use of vacuum tube voltmeters.

In the examples given above the assumption has been made that the base range of the instrument would be that required in the example. This may or may not be a realistic approach, depending on the problem. Many times various problems require instruments with millivolt sensitivity; that is, the capability to measure low values of millivoltage. Other measurements may require that the instrument draw very little current but not have the extremely high millivolt sensitivity. Some manufacturers have developed dual purpose instruments using tapped moving coils. The low resistance tap has lower current sensitivity and lower resistance and consequently, higher millivolt sensitivity, whereas the full winding

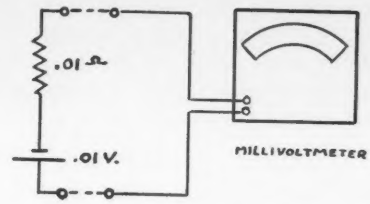


Figure 3—Equivalent circuit of cable section.

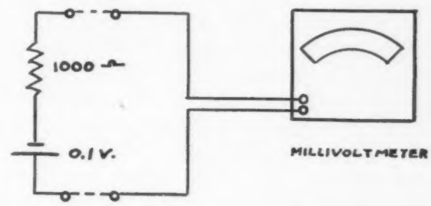


Figure 4—Structure-to-structure equivalent circuit.

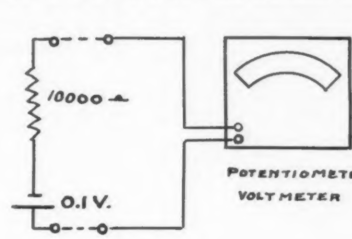


Figure 5

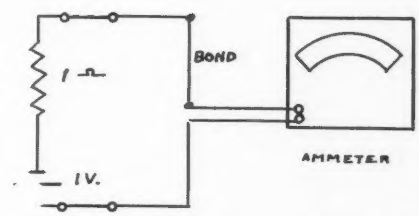


Figure 6—Structure-to-structure equivalent circuit.

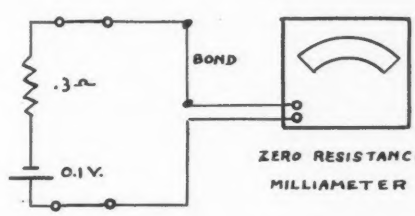


Figure 7

tap has high current sensitivity with the resulting high resistance and lower voltage sensitivity.

Examples of this type of instrument are, for instance, a volt-millivoltmeter, having 1000 ohms per volt on the millivolt ranges, and 5000 ohms per volt on the volt ranges. Another example is the zero center, ultra high resistance DC voltmeter, having sensitivity of 10,000 ohms per volt from 1 millivolt to 10 millivolts and 200,000 ohms per volt on the higher voltage ranges. The duplex electrolysis millivoltme-

ter has approximately 2000 ohms per volt sensitivity on the 1.5/5 millivolt ranges and 50,000 ohms per volt sensitivity from 50 millivolts up to 150 volts. This type of instrument is a satisfactory compromise for most field measurements.

Sensitivity Is Criterion

Experience in instrument design indicates quite clearly that power sensitivity of an instrument as a criterion for its capabilities is a satisfactory approach to the problem of fitting the instrument to the application. Of course, other transcending limitations must be kept in mind. Examples have been given to show the use of the power sensitivity criterion for the capability of an instrument to make measurements with 1 percent instrument insertion error. If larger insertion errors are permissible, it is necessary only to use the correct constants. The important limitation is that of the lowest possible millivolt sensitivity.

A practical working figure for threshold of millivolt sensitivity is 1 millivolt. It also has been illustrated that some deviation from standard voltmeter and current meter circuitry can result in the ability to make accurate measurements beyond the capabilities of the standard instruments. This, of course, is the case with these zero resistance milliammeters and the potentiometer voltmeters.

The field of corrosion measurements and corrosion control is one that challenges the ingenuity of the corrosion engineer. Methods for measurement and for mitigation are subject to revision and modification. In order to supply equipment adequate for this work, manufacturers are willing to cooperate with corrosion workers in development of new methods and new instruments. It is hoped this article will serve as an introduction to the capabilities and limitations of the indicating type instruments used in corrosion work.

Any discussions of this article not published above will appear in the December, 1955 issue.

Design Against Atmospheric Corrosion★

By HENRY T. RUDOLF

ENGINEERING people generally think of corrosion in terms of iron and steel structures rusting and corroding at fairly even rates across the whole of the United States. This generality is untrue in the coastal areas of South Carolina, Georgia and Florida where temperatures of metallic structure will often rise above 150 F in summer and relative humidities above 90 percent are frequent and continued.

Corrosion rates are accelerated in the presence of such temperatures and relative humidities. A temperature rise from 70 to 150 F will increase the rate of combination of iron with oxygen by 150 percent. Increase in relative humidity from 80 to 95 percent increases the rate of rusting another 150 percent. If high temperature and high humidity occur together then a little sea air is added with perhaps some chemical fumes, the destructive effect sometimes can be phenomenal.

One striking example of the destructive effect of the combination of high temperature and high humidity is the apparent rapid breakdown of good protective coatings properly applied and in good thickness. The areas of rapid coating breakdown will be found on steel where coating has been applied over mill scale and almost invariably will be found where the coating is directly exposed to sunlight. The high temperature differential between noon and night may be as much as 90 F. Such a temperature change is sufficient to cause wide variations in the expansion and contraction characteristics of scale and steel. As a result scale and steel frequently part company. A three to five mil coating cannot be expected to have the strength to resist stresses of wind and rain, heat and cold while carrying on its back a dead weight of disadhered mill scale. Necessarily, the coating breaks, corrosive elements attack the structure. The coating takes blame for early breakdown.

This paper is concerned with the design of steel structure.

1. To design with as little surface exposed to corrosion as possible.
2. To design for freedom from corrosion.
3. To design the original cost and maintenance of protective coatings at a minimum.

This will not be an attempt to rewrite the book in basic design. It will be a series of observations, suggestions and recommendations based on practical experience in the field. Necessarily, while the economic impact of the series in fields other than described will not be as heavy, there is little question but that their use over a long period may well be justified and a saving in costs effected.

★A paper presented at a meeting of South East Region, National Association of Corrosion Engineers, Jacksonville, Fla., November 4-5, 1954.

HENRY T. RUDOLF—President of Atlantic Coatings Co., Inc., Jacksonville, Fla. He has a bachelor's and professional engineers' degree from Lafayette College, 1927-1930. Until 1948 was with steel industry in U. S. and abroad in operation, design and construction. Author of papers on and holder of basic patents on blast furnace operation. Since 1948 he has been doing corrosion work exclusively. Founder and first chairman of the Jacksonville, Fla. section of NACE. Member of Sea Horse Institute.

Abstract

Specific recommendations for construction of metallic surfaces exposed to corrosion are made. The author points out total exposed areas may be reduced by adopting the proper shapes of structural members, by enclosing with planar plates structures including angles and braces. Seal welding is recommended.

The design engineer is warned to keep in mind structures exposed to atmosphere ultimately require surface preparation and that an effort should be made to minimize inaccessible areas. Consideration should be given to the need for ultimate painting by providing as many plane surfaces as possible. Welding is favored over riveting. Specific recommendations are made concerning design which offer the best possible way of minimizing corrosion damage.

To Decrease Surface Exposed to Corrosion

Decrease of surface can be accomplished in two ways:

1. Employing shapes of equal design characteristics but lesser exposed area per foot of run.
2. Removing surface from exposure to corrosive influence.

One of the most common of structural combinations is the back to back shape. Angles and channels are the most common combinations and they are cheap, generally available, easy to fabricate and readily replaced when they corrode. The fact that they do corrode readily is a point of corrosion engineer's interest. All back-to-back shapes have the same design fault from a corrosion standpoint, they have foul areas which cannot be cleaned or coated adequately and which set up corrosion hazards. These foul areas are located close between the angles or channels, where cleaning is most difficult and coating almost impossible. Note Figures 1 and 2.

The two most frequently used of the back-to-back

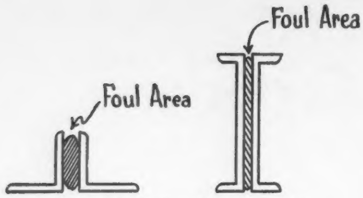


Figure 1, left; Figure 2, right.

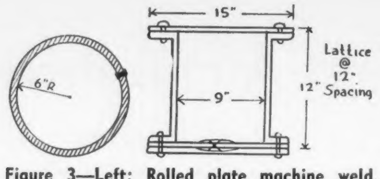


Figure 3—Left: Rolled plate machine weld. Right: Channel plate, lattice bar, open section.

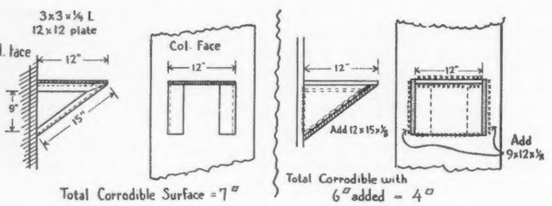


Figure 4

influence altogether. Consider the perimeter of a standard combination-of-shapes tower leg made up of two channels, plate riveted to the channels for a third side and the fourth side a lattice of bars riveted to the channels. If 12-inch channels have been used the total exposure to corrosion per foot of run of such a column can scarcely be less than ten square feet. Whereas a 12-inch diameter pipe sealed at the ends has a total corrosion exposed area of three square feet per foot of run. If the combination shape took three gallons of paint for any unit, the hollow column would take less than one gallon for the same unit. Note Figure 3.

Reducing Corrodible Surfaces

An illustrative example of removing surface from corrosive influence while adding both surface and strength can be the following. Take the case of a small knee braced platform fastened to a column, used perhaps as a motor base, shaft bearing pillow, or a simple pipe bearing. An angle is notched out and bent to form the top bearing and the actual knee brace, two of these angles are welded to the column, a plate is fastened to the tops of the angles and the platform is made. Suppose a 3 x 3 x ¼-inch angle is used and the platform is to be one foot square. The corrodible surface including the area of the column between the angles is about seven square feet. Now, if light plate is used to close in the open triangles formed by the angles and the open rectangle formed by the diagonals, almost six square feet have been added to the structure BUT if all lines of contact are continuously welded the inside of the box is completely sealed away from corrosion and the corrodible, coatable area left is a little less than four square feet. Note Figure 4.

Decrease of exposed surface by active removal of surface from exposure to corrosive influence is largely done by welding. Take the case of two structural members which bear longitudinally on each other throughout their whole length, a channel and an "I" beam for instance. The contact areas are generally in the foul area category, since the contact is so close that cleaning or coating is not practical. Contact often is so close that oxygen concentration cells are set up in addition to more normal rusting forms, the total destructive effect may be abnormal and one shape have to be replaced far earlier than expected. A method to overcome the corroding difficulty is to place a continuous seal weld completely around the area in contact, effectively sealing it away from corrosive influence. Note Figure 5.

shapes, angles and channels can be replaced by single shapes of equal or better design characteristics. A "T" can be substituted for two angles and an "I" can be substituted for two channels. As an illustration—a 4 x 5 inch T can be used to replace two 3 x 3 inch angles with the following design figures. Two 3 x 3 x ¼-inch angles weigh 9.8 pounds per foot of run, a 4 x 5-inch T weighs 8.5 lbs. Two 3 x 3-inch angles have a radius of gyration in x direction of 0.93 and the 4 x 5-inch T is about equivalent. The total exposed area of the two 3 x 3-inch angles is about two square feet per foot of run, of the 4 x 5-inch T, about one and one half. Of much greater importance is the fact that the area between the backs of the angles, 25 percent of the total, is a foul area which cannot be cleaned or coated adequately and which is a source of maintenance trouble all its life. The T on the other hand has no foul area, is readily cleaned and coated, does not harbor corrosion and presents even less area to clean and coat than the shape it replaces. Tees can be cut readily from "I" sections and are usually less expensive than rolled tees. As a rule there will not be extra expense for the "T" since the weight differential about overcomes the shape differential.

Beam Replaces Channels

Another illustration—an 8 x 5½-inch WF beam used to replace two 8 x 2¼-inch back-to-back channels. The design characteristics are about equal, the two channels weigh 23 lb. against 20 lb. for the WF. The total exposed surface of the two channels is slightly over four square feet per foot of run, where the WF is just over three square feet, 33⅓ percent of the channels is foul area, the WF has none at all.

A comparative newcomer to this field of substitution of simple shapes for a combination of shapes is the welded hollow tube, sealed at both ends. The most familiar and striking example of this is the water tower leg made from rolled plate and welded. With this substitution surface is not only decreased, but half the total surface is removed from corrosive

Seal Welding Techniques

At this point it is necessary to define the term seal welding since it differs from standard forms of welding and is not provided for in current handbooks on welding, although some welding authorities agree it should be. The primary purpose of a seal weld is to

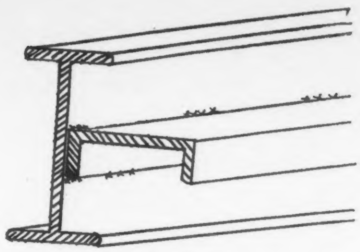
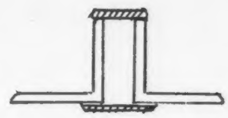


Figure 5



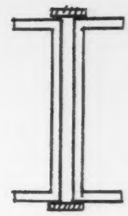


Figure 6, left; Figure 7, right.

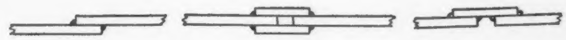


Figure 8

provide a metallic seal between two surfaces to prevent incursion of gases or fluids; the secondary purpose of a seal weld is to provide a fastening between two surfaces.

Standard joint welds have a computed strength based on penetration, reinforcement and strength of materials per unit of welding length. Seal welds have much less designed strength per unit of welding length. Standard welds are not as a rule made continuous when they are for the sole purpose of fastening. More usually the line of contact of the surfaces to be fastened is welded and skipped, welded and skipped. (Corrosionwise skip welding is anathema, the unwelded contact line draws oxygen and water between the contacting surfaces as they differentially expand or contract and no coating, no matter how flexible, can stand continual differential movement of two surfaces, thus air and moisture can enter at the unwelded contact line and corrosion is increased materially at these points. A notable example of this is the lower edge of the stiffener angles usually welded to the top of the cylinder of an open roof tank. No matter how much painting is done the rust stains continue at the lower open edge.) From the standpoint of dollars and cents standard joint welds cannot be made continuous for the sole purpose of sealing in an area or a volume, however seal welds which use less material and less time per unit of weld length can be economical.

On any member of primary importance in a structure where designed weld strength is vital and skip welding is the accepted method of fastening, the author suggests the standard practice of skip welding plus seal welding between the skips, offsetting the increased cost of the overall welding by the decreased cost of corrosion on the areas thus sealed away.

Undesirable Stresses Avoided

There is one advantage of seal welding over standard joint welding which is true with lighter section or secondary steel. Standard welding penetration is inclined to warp lighter members during cooling, a secondary corrosion probability is set up due to the crystal changes in the metal which may vary local potentials sufficiently to set up anodic-cathodic areas. Seal welding with shallower penetration using lighter rod moving at greater welding speeds does not disturb the metal so deeply, scarcely ever warps and lessens the tendency toward secondary corrosion.

A method of saving fouled structures already in place is to blast out the majority of corrosion products, seal in the volume between the members with straps top and bottom, weld sealed into position, not forgetting to seal in the ênd of the hollow box thus formed. Once the box is sealed in corrosion will stifle itself in comparatively short time. Note Figures 6 and 7.

A method of converting combination-of-shapes water tower legs into hollow box legs is to take off the lattice bars, blast out the worst of corrosion products and seal weld light plate on the lattice side of the two channels, taking care also to seal weld the top and bottom of the hollow column thus formed. The surface now necessary to maintain is roughly half what it was before, only half the amount of coating is necessary since half of the total corroding surface has been sealed off.

Freedom from Initial Corrosion

Corrosion often starts on structural steel before it has been delivered to site, long before erection. Corrosion centers will be found in the vicinity of sheared edges, reamed or punched holes, partially deformed areas from which mill scale has been popped and join lines of riveted members. While these centers are definite, it does not mean that if the structure later fails from corrosion it will fail from corrosion started at these centers. It may mean only that these preliminary oxidation points have taken on a protective coat of oxide which will effectively prevent the inroads of further corrosion.

The designer's desire is to so design that without protective coatings early corrosion will be prevented. The cardinal principle here is smooth flow of surface. Traps, pockets, sharp edges and acute angles are to be avoided where possible. The very wide use of welding instead of riveting is of great help because it permits the use of rounded instead of square corners, sealed joints instead of open ones. Any rivet exposed to dust and dampness when joining two members is an invitation to concentration cell corrosion. The presence of even a small bit of mill scale in contact with the rivet invites galvanic corrosion. Any two bodies of different section thickness will expand and contract at different rates. If the bodies are riveted together the differential expansion produces a sort of breathing which brings fresh oxygen and/or moisture to the contacting surfaces and corrosion cells are set up. If the bodies are seal welded together, breathing cannot take place and corrosion between the surfaces is avoided.

Examples Improving Smooth Flow

A few random examples of welding to improve smooth flow, and to avoid crevice corrosion follow:

When an angle is welded to a plate all contacting edges should be seal welded.

When a bent plate instead of an angle is welded to a plate, the entire line of contact should be welded on all edges.

When a plate is welded to a plate at right angles, continuous welds on both sides of the plate should be made.

Lap welded plates should be welded solid on both open seams.

Strap welded plates, whether double or single should be welded on all four open seams. Note Figure 8.

When a curved plate is welded to a flat plate at a tangent, the weld should be made on three sides solid and on the fourth side a triangular filler should be welded in to seal off the entire contact.

Low Cost of Maintenance

Designing to decrease the cost of protective coatings and their maintenance is largely a matter of combining the two previously mentioned design principles. Necessarily there are some aids to the painter advantage of which should be taken by the designer. The painter wants several things to aid him in supplying a good coating of designed thickness, with complete continuity of coat, excellent adhesion, at low cost. First, he wants low cost surface cleaning, whether it be sandblasting, power brushing or other physical form. Then he wants as nearly a continuous plane surface as he can get to which to apply his coating. Finally, he wants his surface accessible.

All structural designers should keep in mind that at some future time the structure they are designing might have to be sandblasted. Some elements of design do not lend themselves to clearing out of corrosion products, no matter what the means employed. For instance, it is practically impossible to clear the products of corrosion from beneath a rivet head, unless corrosion has proceeded to a stage where the contact area of the rivet head is wholly rusty, then the rivet head does not bear and the fastening is lost. It is better to seal weld the rivet all around than to attempt to blast out rust if corrosion has proceeded to an advanced stage. Seal welding may quite successfully stifle the corrosion process and leave the rivet effective as a fastening.

The contact area of plates joined by riveting is in about the same category as the rivet head, sandblasting is ineffective, corrosion products are left in place and unless the rusting is stifled by seal welding, it will ultimately build up sufficient volume to break through a coating.

Proper sandblasting of an erected structure is a considerable undertaking, even on an all-welded structure. There will be sharp cul-de-sac angles in which it is impossible to get a fair angle of sand impingment and the surface will look clean from one line of sight and dirty from another 90 or 180 degrees away. This is caused by the sand impingment on only one side of pores and pits in the steel. Areas of this type will show early coating failure due to simple improper cleaning which the painter cannot avoid. The designer should consciously attempt to get continuous plane surfaces without sharp breaks. He may use weld filling, filleting, edge grinding or deformed shapes. Welds should in all cases be smoothed to some degree, needles and spatter should definitely be ground off.

Drainage Is Important

One further point should be noted on the part of the designer, this is the matter of drainage of moisture from every part of the structure. Angular coupling of shapes usually provides some sort of haven for moisture which cannot drain away but has to evaporate in place. Angle, channel or "I" beam should never be placed to leave a sort of vessel to retain moisture. Either the position of the shape should be changed or drain holes cut to provide rapid movement of moisture downward away from the piece. With good drainage of all members of a structure, one of the strongest measures of corrosion mitigation has been taken.

One further suggestion to the designer—any installation which provides circular instead of square characteristics to either an element or the whole of a structure works these economic aids. Less perimeter means less total surface, less to supply, less to corrode, less to clean, less to coat. The circular shape tends to provide better continuity of surface, better able to hold and maintain an even coating thickness, better able to resist corrosive factors, better able to be cleaned.

Finally, if the designer could engrave on his structure and in the mind of the owner the words "Keep me clean," he would have done more to mitigate corrosion than all the design changes in history.

Any discussions of this article not published above will appear in the December, 1955 issue.

Stress Corrosion Cracking Of Hardenable Stainless Steels★

By F. K. BLOOM

Introduction

THE HARDENABLE straight-chromium stainless steels, like other hard steels may be susceptible to cracking when acid pickled. Such cracking, which occurs under the combined action of locked-in quenching stresses and corrosion is well known and usually has been attributed to hydrogen embrittlement. Until recently reports of failures of these steels in normal service environments have been rare, although they have been employed in large tonnages in many applications.

The literature disclosed only a few references to spontaneous cracking of martensitic stainless steels in corrosive environments. Ffield[1] and Gerard[2] both report spontaneous cracking in Zeppelin structural members hardened and cold formed from .20% C-13.0% Cr strip exposed to sea water or salt spray. It is noteworthy that the alloy was used successfully in the British R-101 airship as tubular members produced with minimum internal stress by cold forming annealed strip, then hardening and stress-relieving. Uhlig[3] conducted laboratory tests on hardened and severely cold drawn 12% Cr-1% Cu wire which cracked under stress in salt water very rapidly when coupled to aluminum or charged with hydrogen cathodically.

At a symposium on "Sulfide Stress Corrosion"[4] in 1952 several technical papers were presented relating to laboratory and field testing of high-strength alloys under conditions comparable to those in sour gas condensate wells. Such wells produce hydrogen sulfide and carbon dioxides at high pressures and brittle failures of tubing occurred in several instances. A number of high-strength steels were found susceptible to cracking under static stress when exposed to acidic solutions containing hydrogen sulfide, including the 12 percent chromium stainless steel, Type 410.

In 1953 a gas turbine manufacturer reported[5,6] cracking of hardened and tempered 12 percent chromium (Type 403) compressor blading. Moisture condensed in the cooler end of the compressor was suspected. Accelerated laboratory tests in a severe medium of hydrochloric acid containing selenium oxide, to promote embrittlement, produced cracking of a similar nature when samples were externally tension stressed to 100,000 psi and their hardness was in the order of Rockwell C30 or above.

Other cases of stress corrosion cracking of hardenable grades subsequently were brought to Armco laboratories' attention. Roller chain side bars of hardened 12 percent chromium (Type 410) were found to crack when exposed in 7 percent salt spray. It was reported also that hardened 13% chromium-.30% carbon (Type 420) drive screws used to attach aluminum roofing had cracked rapidly in service. Lincoln[7] stated in a technical paper that hardened Type 420 would crack in the atmosphere and Type 410 in 3 percent salt solutions.

F. K. BLOOM—Research Metallurgist with the Baltimore Section of the Armco Research Laboratories, has been engaged in the study of problems relating to the heat treatment, welding, fabrication and corrosion resistance of stainless steels. He has been active on many committees and groups dealing with specifications for these steels and has been the author or co-author of several technical papers relating to their mechanical properties and corrosion resistance. After graduation from George Washington University in 1935 he joined the Rustless Iron and Steel Corporation, now the Baltimore Works of Armco Steel Corporation, which is devoted exclusively to the manufacture of stainless steels.

Abstract

Hardenable stainless steels, like other high-strength steels, are susceptible to cracking under the combined influence of tensile stress and corrosion, depending on the severity of the stress, the nature of the media and to a large extent, on their hardness. The most severe conditions are acid solutions containing sulfides, which promote entry of hydrogen into the steel and where chlorides are present to promote pitting. In such media cracking may occur in the standard grades under stress at hardnesses of Rockwell C24, in severe marine atmospheres at C40 and in industrial atmospheres at C45. Type 422, a modified 12 percent chromium alloy, tempered at 1200 F to Rockwell C30 and the precipitation-hardening alloys, 17-4 PH and 17-7 PH, overaged to the same hardness level were the most resistant materials tested.

Types 410, 416 and 431 performed as well as or somewhat better than low alloy steels when heat treated to equivalent hardness levels. Tempering them at 1100 F or higher temperatures provided good resistance to cracking in the severest media.

Internal stresses generated during quenching can promote stress corrosion cracking without imposing additional external stresses. Interrupted quenching (martempering) is helpful in minimizing stresses from this source and is recommended as a heat treating practice for valve trim and other parts used fully hardened in service likely to cause corrosion cracking.

An investigation was begun in 1952 to explore the effect of heat treatment on the susceptibility of Type 410 to cracking in hydrogen-sulfide solutions. As other reports of stress corrosion cracking were received the project was expanded to include a number of corrosive media and a variety of hardenable stainless steels.

Materials, Media and Test Procedure

For comparison the important standard hardenable grades of stainless steel, Types 410, 416, 431, 440A and 440C were selected. These provided a wide range of quenched hardness. A modified 12 percent chromium alloy containing molybdenum and tungsten, Type

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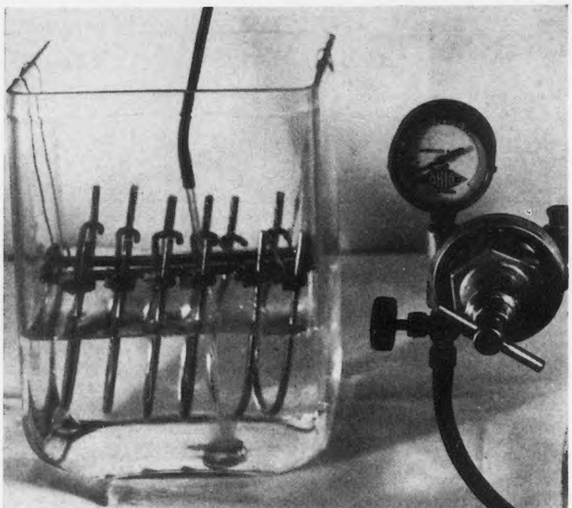


Figure 1—Method of exposing horseshoe type samples to laboratory test media.

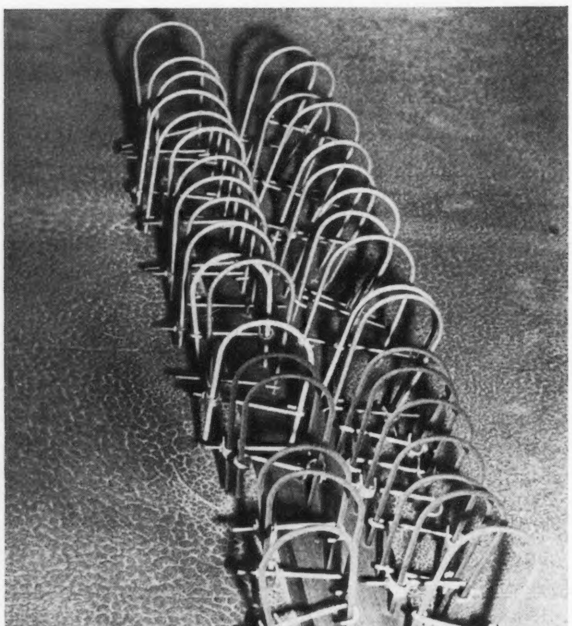


Figure 2—Method of exposing horseshoe type samples in atmosphere.

422 also was included since it was reported more resistant to cracking.[6] The new 17-4 PH and 17-7 PH precipitation-hardening type alloys used as high-strength materials in aircraft and similar applications were examined also.

To determine whether high-strength austenitic alloys were similarly susceptible to cracking, tests were performed on 17-10 P, a nonmagnetic austenitic alloy hardened by precipitation heat treatment. Types 304 and 305 were tested in the form of wire cold drawn to high tensile strength, one being mag-

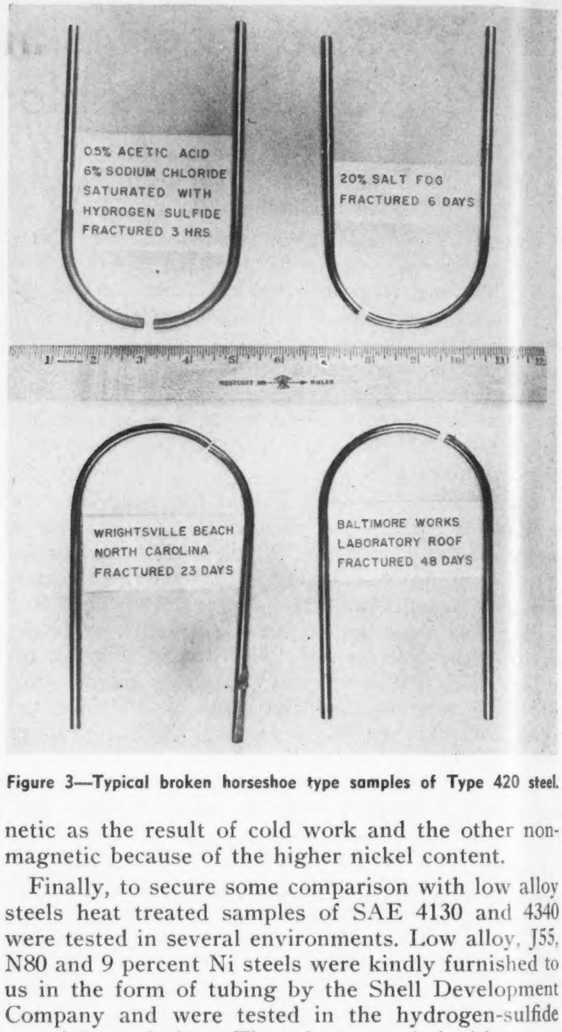


Figure 3—Typical broken horseshoe type samples of Type 420 steel.

netic as the result of cold work and the other non-magnetic because of the higher nickel content.

Finally, to secure some comparison with low alloy steels heat treated samples of SAE 4130 and 4340 were tested in several environments. Low alloy, J55, N80 and 9 percent Ni steels were kindly furnished to us in the form of tubing by the Shell Development Company and were tested in the hydrogen-sulfide containing solutions. These latter steels had been extensively studied by others and were known to vary considerably in susceptibility of failure in sour condensate well service.

The chemical analysis of all materials is shown in Table 1.

The environments selected for testing were chosen on the basis of previous investigations by others. Laboratory tests were conducted on most of the materials in a solution of distilled water containing ½ percent acetic acid (HAc) periodically saturated with hydrogen sulfide. The same solution also was used containing in addition, 6 percent sodium chloride. These media were originated by the Shell Development Company and simulated conditions causing cracking in sour gas condensate wells. Laboratory tests in 20 percent salt fog and in an aqueous 6 percent sodium chloride solution were based on the work of Ffield and Uhlig.

In addition, most of the materials were exposed to two types of atmospheres. Samples were installed at the International Nickel Company's Harbor Island Experimental Station, North Carolina in an open lo-

cation about 200 feet from Wrightsville Sound in a relatively severe marine atmosphere. A second group was placed in an open location on the laboratory roof at Baltimore subject to fumes from the plant and chemical laboratory hoods, a severe industrial atmosphere.

Two methods of testing were adopted. In most cases a simple horseshoe-shaped sample was used, formed from annealed wire ¼-inch in diameter, heat treated, descaled without contacting acids and polished. These samples were loaded to a nominal outer fibre stress of 100,000 psi by pulling the legs of the horseshoe together with a Type 316 wire clamp. The method of exposing them in the laboratory and to the atmosphere is shown in Figures 1 and 2. Figure 3 shows the appearance of typical failed samples.

The choice of 100,000 psi stress was more or less arbitrary. The work of Treseder,[8] Badger,[6] and others had shown that this stress was quite sufficient to produce cracking in their alloys which they investigated and could be considered a high level of stress in any service. Horseshoe samples of this type were tested in triplicate and the time to failure recorded in days because often the exact time of fracture could not be established conveniently.

The second method provided a precise means of applying a known tension stress to the sample. Six special machines were constructed, patterned after equipment used for high-temperature creep and rupture testing. Tensile type specimens were deadweight loaded by levers. The specimens were surrounded by cans containing the corrosive media. Time to failure was automatically clocked to the nearest tenth of an hour. The machines and method of stressing the samples are shown in Figures 4 and 5 and typical fractured samples, in Figure 6.

All samples were prepared from centerless ground wire free from decarburization. Hardening and tempering were done in electric muffle furnaces in air. Initially, samples were quenched from the hardening temperature in oil at room temperature. Later it was found desirable to martemper by quenching into molten salt at 600 F, holding 10 minutes and air cooling to minimize internal stresses.

Afterwards the horseshoe samples were descaled by immersion in a 10 percent sodium hydroxide-3 percent potassium permanganate solution, polished lightly with 120-grit emery paper and then electro-

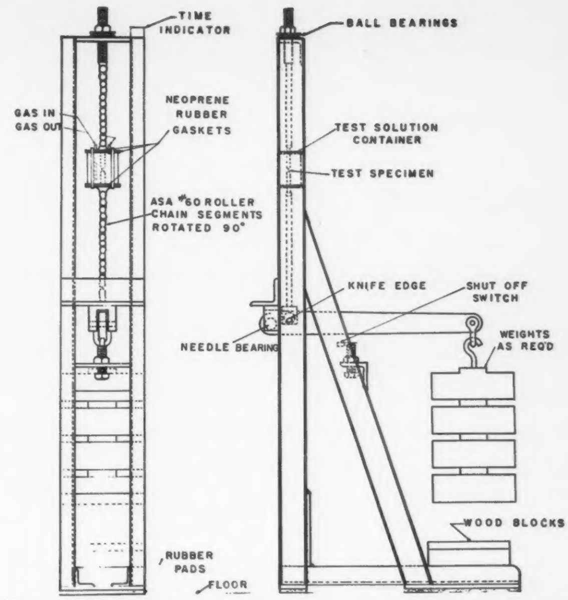


Figure 4—Diagram of direct tension test machines showing method of loading.

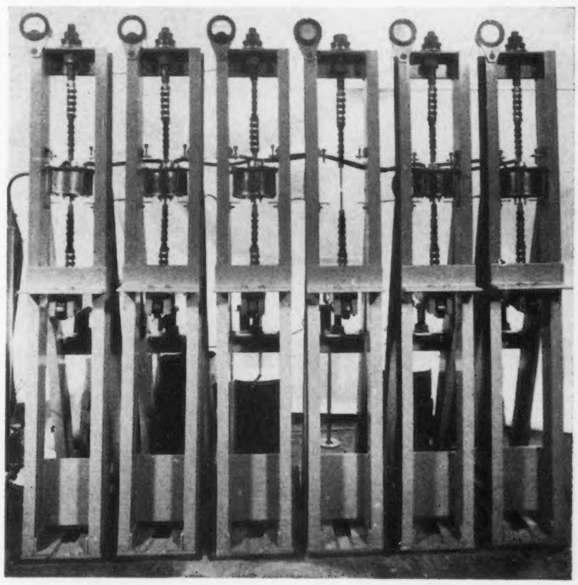


Figure 5—Appearance of six test units. Five test samples are surrounded by cans containing corrodent.

TABLE 1—Chemical Analyses of Materials Used in Various Tests

TYPE	Heat No.	Test Data in Tables	C	Mn	P	S	Si	Cr	Ni	Al	Cu	Mo	W	V
410	22371	2, 3, 6	.101	.49	.019	.022	.33	12.35	.22	....	....	.50	....	....
416	11831	2, 3	.104	.68	.024	.280	.49	12.54	.20	....	....	....	....	....
431	22694	2, 3	.150	.66	.018	.022	.33	16.18	1.66	....	....	....	....	....
17-4PH	32715	2, 4, 6	.034	.48	.022	.012	.38	16.32	4.62	....	3.12	....	....	....
17-4PH	32467	2	.052	.53	.023	.013	.40	16.38	4.33	....	3.69	....	....	....
17-7PH	32680	2, 5, 6	.069	.77	.036	.012	.42	17.33	7.16	1.08	....	....	....	....
420	22271	2	.367	.37	.016	.033	.50	13.28	.26	....	....	....	....	....
440A	42101	2	.680	.49	.022	.028	.39	17.49	.31	....	....	....	....	....
440C	11904	2	.984	.48	.020	.012	.59	17.46	.18	....	....	....	....	....
17-10P	32699	2	.123	.88	.272	.007	.55	17.33	10.66	....	....	....	....	....
304	63373	2	.052	.58	.021	.017	.49	18.59	9.45	....	....	....	....	....
305	22944	2	.066	.72	.027	.015	.45	18.41	11.50	....	....	....	....	....
SAE 4130	.....	2	.27	.54	....	....	.25	1.27	....	....	....	.18	....	....
SAE 4340	.....	2	.39	.69	....	....	.27	1.06	1.89	....	....	.22	....	....
410	23734	6	.096	.49	.017	.018	.34	12.65	.19	....	....	.53	....	....
422	33980	6	.20	.69	.018	.019	.39	13.12	.79	....	....	1.08	1.11	.25
J55	.....	6	.51	1.10	.024	.022	.21	....	....	....	....	....	....	....
N80	.....	6	.38	1.31	.007	.020	.25	....	....	....	....	.31	....	....
9% Ni	.....	6	.15	.63	.010	.024	.36	.17	8.43	....	....	....	....	....

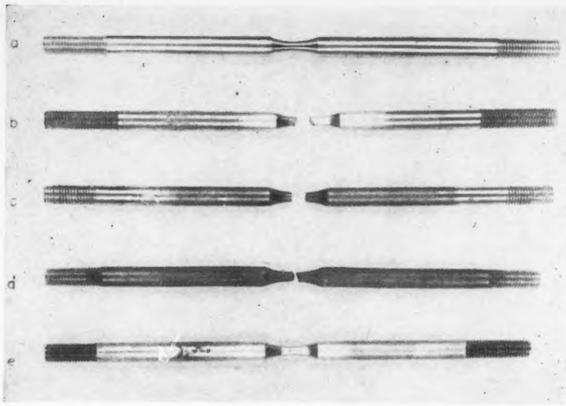


Figure 6—Appearance of typical direct tension test specimens fractured by ½% acetic acid plus hydrogen sulfide. a. Type 410 not tested. b. Type 410 fractured in 152.9 hours at 90,000 psi. c. 4340 fractured in two hours at 100,000 psi. d. N 80 fractured at 11.3 hours at 70,000 psi. e. 17-4 PH not fractured at 1006.8 hours at 100,000 psi.

polished. Early specimens then were further polished by mechanical buffing to remove any possible stress raisers from the surface but this final buffing did not seem to improve the reproducibility of test results and was abandoned.

Tensile specimens were descaled as above but were not electropolished .The reduced section in the center was polished by hand to a 000-emery finish.

Discussion of Results

A. *Horseshoe Tests Comparing Various Grades and Media.*

Table 2 lists the results of tests on horseshoe type, fixed deflection samples from a variety of grades initially stressed to 100,000 psi and exposed in the following six media at room temperature:

1. ½% HAc + H_2S + 6% NaCl solution—500 hours
2. ½% HAc + H_2S solution—62 days
3. 20% salt fog—1000 hours
4. 6% salt solution—1000 hours
5. Marine atmosphere—Harbor Island, N. C.—550 days
6. Industrial atmosphere—Laboratory roof, Baltimore, Md.—580 days

Except for the SAE steels, none of the samples included in this series of tests was martempered. All quenching was done in oil at room temperatures. It was observed subsequently that internal stresses set up by this operation were high enough to cause cracking in the acetic acid-hydrogen sulfide-sodium chloride media without the presence of additional external stress. In all further work quenching stresses were minimized by martempering, that is, by quenching into molten salt near the M_s transformation tem-

TABLE 2—Comparison of Various Grades in Different Media

Horseshoe type samples, stressed to 100,000 psi, tested in triplicate

Legend—X—Sample fractured spontaneously. C—Sample cracked but did not fracture. OK—Sample did not crack or fracture. Numbers following symbols show range of time to failure for three samples.

Grade	Heat No.	Treatment Degrees F	Rockwell Hardness	MEDIA: ½%HAc+H_2S +6%NaCl, Hours	½%HAc+H_2S, Days	20% Salt Fog, Days	6% Salt Sol., Days	ATMOSPHERE: Harbor Isl., Days	Lab. Roof, Days
440C	11904	1900–oil+600–air	C54—55	3 X 1–2	3 X 1–2	3 X 1–2	3 X 1–2	3 X 7–16	3 X 3–11 3 X 22–29
440A	42101	1900–oil+600–air	C52—53	3 X 1–2	3 X 5–5	3 X 2–3	3 OK 42	3 X 16–27	3 X 13–54
420	22271	1900–oil+600–air	C50—52	3 X 2–5	3 X 2–3	2 X 3–7 1 OK 42	1 X 14 2 OK 42	3 X 16–23	3 X 29–335
17-7PH	32680	Ann. + 1400–air+950–air	C44—45		3 X 1–2			3 X 21–120	1 X 218 2 OK 240
	32680		C44—46	3 X 1–2	3 X 4–24	3 X 2–17	1 C 42 2 OK 42	3 X 101–110	1 X 369 2 OK 580
17-4PH	32715	Ann. + 900–air	C41—43		1 X 2 2 OK 50			3 X 21–23	3 OK 240
	32467		C44—45	3 X 6–46	2 X 12–38 1 OK 62	3 OK 42	3 OK 42	3 X 49–66	3 OK 580
431	22694	1800–oil+600–air	C42—43	3 X 30–46	2 X 57 1 OK 62	3 OK 42	3 OK 42	3 OK 550	3 OK 580
410	22371	1800–oil+600–air	C41—43	3 X 6–21	3 X 8–8 3 X 3–5	3 OK 42	3 OK 42	3 OK 550	3 OK 580
416	11831	1800–oil+600–air	C40—42	3 X 30–46	3 X 3–5	3 OK 42	3 OK 42	3 OK 550	3 OK 580
17-7PH	32680	Ann. + 1400–air+1050–air	C41—43	3 X 1–5	3 X 1–5	3 OK 42	3 OK 42	3 OK 550	3 OK 580
17-4PH	32467	Ann. + 1200–air	C29—31	2 X 282 1 C 504	3 C 62	3 OK 42	3 OK 42	3 OK 550	3 OK 580
304	63373	Cold Drawn 56%	C42—42	3 C 504	3 OK 62	3 OK 42	3 OK 42	3 OK 550	3 OK 580
305	22944	Cold Drawn 56%	C34—34	3 C 504	3 OK 62	3 OK 42	3 OK 42	3 OK 550	3 OK 580
17-10P	32699	Ann. + 1300–air	C30—30	2 X 101–432 1 C 504	3 OK 62	3 OK 42	3 OK 42	3 OK 550	3 OK 580
SAE 4130	.....	600+600–air 900–air	C27—28		3 X 2–7	3 OK 42		3 OK 300	3 OK 300
SAE 4130	.....	1600+600–air 1100–air	C21—21		3 OK 42	3 OK 42		3 OK 300	3 OK 300
SAE 4340	.....	1500+650–air 900–air	C36—36		3 X 1–1	3 OK 42		3 OK 300	3 OK 300

perature, then air cooling. In this series the quench-hardened stainless steels, therefore, were exposed with a severe combination of internally and externally applied stress.

Although every steel tested cracked in at least one of the media, there were appreciable differences in the severity of the media and in the susceptibility of the various grades. Hardness bore some but not an exact relation to cracking sensitivity.

Media No. 1, suggested by the Shell Development Company was the most severe and even caused cracking in the cold worked austenitic alloys. Shell's medium No. 2 also was very severe and cracked all hard steels tested except the austenitic grades. Since it gave a broad spread in failure times between the different grades and was more discriminating in this sense, it was used most often in the later work. Both media caused cracking in stressed stainless steels at hardness levels around Rockwell C30 and higher and in the low alloy SAE 4130 steel at C27. Standard salt fog and 6% salt solution cracked stressed steels only when their hardness was about C45 or higher. In the marine atmosphere the hardness level at which cracking occurred was somewhere between Rockwell C40 and 45, depending on the grade of steel and between C45 and 50 in the severe industrial atmosphere.

The highly hardenable grades, Types 440C, 440A, 420 and 17-7 PH aged to its maximum hardness, were susceptible to cracking in all six environments. Overaging 17-7 PH at 1050 F resulted in a marked improvement. 17-4 PH aged at 900 F to its peak hardness was less susceptible than 17-7 PH. It was improved also by overaging and this was explored in more detail in another series of tests. Types 410, 416, 431 and SAE 4130 and 4340 cracked only in the severe hydrogen sulfide tests. None of these cracked in either atmosphere. The cold drawn austenitic Types 304 and 305 were found to be cracked after 500 hours in the most severe Shell medium. Armco 17-10 P, precipitation-hardened to Rockwell C30, also fractured in this medium but its performance was generally better than that of martensitic alloys at the same hardness level.

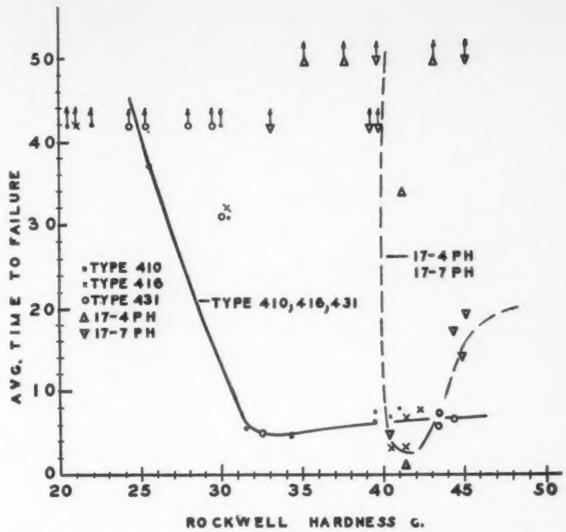


Figure 7—Relation between hardness and time to failure in ½% HAc plus hydrogen sulfide solution.

TABLE 4—Effect of Varying Aging Treatments on 17-4 PH

Horseshoe type samples, stressed to 100,000 psi, tested in triplicate

Legend—X—Sample fractured spontaneously. C—Sample cracked but did not fracture. OK—Sample did not crack or fracture.

Preliminary Treatment—Mill annealed 1900 F + Aged as shown

Heat No. 32715 C—.034 Cr—16.32 Ni—4.62 Cu—3.12

Aging Temp. F	Rockwell Hardness	½%HAc+H₂S 50 Days	Harbor Island 230 Days	Lab. Roof 240 Days
800	C41—42	3 X 1–2	2 X 15–71; 1 OK 230	3 OK 240
900	C41—43	1 X 2; 2 OK 50	3 X 21–23	3 OK 240
950	C43—44	3 OK 50	1 X 197; 2 OK 230	3 OK 240
1000	C37—39	3 OK 50	3 OK 230	3 OK 240
1050	C35—36	3 OK 50	3 OK 230	3 OK 240
1100	C35—36	3 OK 50	3 OK 230	3 OK 240

TABLE 3

Effect of Varying Tempering Temperature on Types 410, 416, and 431

Horseshoe type samples, stressed to 100,000 psi, tested in triplicate

Legend—X—Sample fractured spontaneously. C—Sample cracked but did not fracture. OK—Sample did not crack or fracture.

All samples hardened 1800 F—20 min.—quenched in salt at 600 F—held 20 minutes—air cooled—followed by tempering for 4 hours and air cooling as shown below.

	TYPE 410		TYPE 416		TYPE 431	
	Heat No. 22371 C-.101 Cr-12.35		Heat No. 11831 C-.104 Cr-12.54		Heat No. 22694 C-.150 Cr-16.18 Ni-1.66	
Tempering Temp. Degrees F	Rockwell Hardness	½%HAc+H₂S Days	Rockwell Hardness	½%HAc+H₂S Days	Rockwell Hardness	½%HAc+H₂S Days
200	C39–40	3 X 4–8	C41–42	3 X 7–7	C44–45	3 X 7–7
400	C39–40	3 X 7–8	C42–43	3 X 8–8	C43–44	3 X 7–8
600	C40–42	3 X 8–8	C40–41	3 X 3–3	C43–44	3 X 2–8
800	C40–41	3 X 7–7	C41–42	3 X 3–3	C43–44	3 X 8–8
1000	C31–32	3 X 5–6	C31–31	3 X 30–33	C32–33	3 X 5–6
1025	C30–31	3 X 31–33	......	....	C30–30	3 X 31
1050	C30–30	3 OK 42	......	....	C29–30	3 OK 42
1075	C25–26	2 X 21–38; 1 OK 42	......	....	C28–28	3 OK 42
1100	C22–23	3 OK 42	......	....	C28–28	3 OK 42
1200	C21–22	3 OK 42	B98–99	3 OK 42	C25–26	3 OK 42
1400	B92–93	3 OK 42	B88–89	3 OK 42	C24–25	3 OK 42

B. *Horseshoe Tests Comparing Tempering or Aging Temperature and Hardness of Types 410, 416, 431, 17-4 PH and 17-7 PH.*

Tables 3, 4 and 5 contain the results of tests on horseshoe samples tempered or overaged at various temperatures. Types 410, 416 and 431 were martempered prior to tempering and tested in the ½% HAc—H_2S solution. The precipitation-hardening grades, 17-4 PH and 17-7 PH were tested also by exposing them at Harbor Island and on the laboratory roof.

In the case of the quench-hardenable grades, samples tempered at 1050 F and above did not crack within a test period of 1000 hours. Tempered below this level, all samples ruptured and the time to failure showed no clear relation to tempering temperature. Figure 7 shows the effect of hardness on time to failure and the sharp improvement when the hardness of the three grades fell below Rockwell C25.

Aged at 1000 to 1100 F, 17-4 PH did not crack in any of the three exposures and has not cracked in the severe industrial atmosphere even when aged to its maximum hardness. When aged at 1200 F this alloy did not break under stress in acetic acid-hydrogen sulfide but did develop numerous fine cracks. This treatment is slightly above the critical temperature for this grade and cannot be properly regarded as overaging. 17-7 PH did not crack in any exposure when underaged at 850 F or when overaged at 1100 to 1150 F. It is significant that when aged at 1050 F it has not cracked in over a year and a half at either Harbor Island or on the laboratory roof, despite its high level of hardness.

C. *Direct Tension Tests Comparing Various Grades and Varying Stress Level*

The data obtained so far are in Table 6. This study was primarily to compare stainless steels with other materials used in sour gas condensate well service. An attempt has been made to find the maximum useful hardness and stress level for Type 410. Since the overaged precipitation-hardening alloys showed promise in the horseshoe tests, they also were investigated. Tests were conducted on the modified 12 Cr alloy containing small amounts of nickel, molybdenum, tungsten and vanadium (Type 422) since it was reported by Badger[6] to be less susceptible to this type of cracking.

All samples of the quench-hardened grades were martempered to minimize internal quenching stresses.

While the data are not complete, enough have been obtained to provide comparison of the alloys

TABLE 5—Effect of Varying Aging Treatments on 17-7 PH

Horseshoe type samples, stressed to 100,000 psi, tested in triplicate

Legend—X—Sample fractured spontaneously. C—Sample cracked but did not fracture. OK—Sample did not crack or fracture.

Preliminary Treatment—Mill annealed 1900 F + 1400 F 1 hr.—cool to 60 F + Aged as shown

Heat No. 32680 C—.069 Cr—17.33 Ni—7:16 Al—1.08

Aging Temp. Degrees F	Rockwell Hardness	½%HAc+H_2S 42 Days	Harbor Island 240 Days	Lab. Roof 230 Days
850	C39—40	3 OK 42	3 OK 240	3 OK 230
950	C44—45	3 X 16-18	3 X 21-120	3 OK 230
1000	C46—47	3 OK 42	1 X 163 2 OK 240	1 X 218 2 OK 230
1050	C45—46	3 X 16-19	3 OK 240	3 OK 230
1100	C40—40	3 OK 42	3 OK 240	3 OK 230
1150	C33—34	3 OK 42	3 OK 240	3 OK 230

TABLE 7

Grade	Rockwell Hardness	Time to Fracture at 100,000 psi Hours	Approximate Lowest Stress at which 2 out of 3 did not Fail: In Actual psi	Approximate Lowest Stress at which 2 out of 3 did not Fail: In Percent of Yld. Str.
9% Ni	C30	3–4	<50,000	<35
N80	C25	2	50,000–70,000	60-85
J55	B93	2	50,000	95
4340	C32	2–13	....	..
410	C40	2- 98- 136	50,000	35
410	C32	115–123–126	....	..
422	C30	364–1024*–1554*	90,000	70
17-4 PH	C32	556–1002*–1078*	100,000	70
17-7 PH	C31	99–1127*–1127*	100,000	85

* Sample did not fail and test stopped at indicated time.

TABLE 6—Direct Tension Test

Effect of Varying Stress Level on Various Grades

Specimens loaded in tension, exposed to ½% HAc saturated with H_2S

						MECHANICAL PROPERTIES					STRESS CORROSION TEST	
Grade	Heat No.	C	Cr	Others	Treatment Degrees F	Rockwell Hardness	Ult. Tens. Str. psi	.2% Yld. Str. psi	Elon. 4xd Percent	Red. Area Percent	Applied Stress psi	Time to Failure Hours
410	22371	.101	12.35	Mo–.50	1800+600–air +600–4 hrs.–air	C40	197,700	168,100	15	62	100,000 90,000 80,000 70,000 60,000 50,000	2- 98- 136 2- 43- 153 23- 69- 136 97- 220- 1500* 1500*–1459* 868- 1081*–1294*
410	23734	.096	12.65	Mo–.14	1800+600–air +1010–4 hrs.–air	C32	146,800	137,000	18	69	100,000	115- 123- 126
422	33980	.20	13.12	Ni–.79 Mo–1.08 W–1.11 V– .25	1875+600–air+ 1200–9 hrs.–air	C30	149,000	128,500	21	57	110,000 100,000 90,000 80,000	14- 49 202- 1298*–1504* 364 –1554*–1024* 1510*
17-4PH	32715	.034	16.32	Ni–4.62 Cu–3.12	1900+600–air+ 1150–4 hrs.–air	C32	148,600	139,000	15	63	110,000 100,000 90,000	106 –1050* 556 –1002*–1078* 1040*–1040*–1010*
17-7PH	32680	.069	17.73	Ni–7.16 Al–1.08	1900–water+ 1400+60+1150– 4 hrs.–air	C31	148,000	111,500	19	50	110,000 100,000	468 99 –1127*–1127*
J55	Tube	.51	....	Mn–1.10	As rec'd.	B93	107,200	57,800	19	53	100,000 70,000 50,000	2 10 330 –1504*–1004*
N80	Tube	.38	....	Mn–1.31 Ni– .31	As rec'd.	C25	108,300	81,900	..	55	100,000 70,000 50,000	2 11 1268*–1073*
9%Ni	Tube	.15	....	Ni–8.43	As rec'd.	C30	149,300	138,200	24	66	100,000 50,000	3–4 24–57
4340	Bar	.39	1.06	Ni–1.89 Mo– .22	1500+350–air+ 1075–1 hr.–air	C34	156,700	150,500	19	32	100,000	2–13

* Sample did not fail and test stopped at indicated time.

and indicate the effect of stress level. The data in Table 7 are from Table 6 compare several steels on the basis of time to fracture at a fixed stress level of 100,000 psi. Where possible, an attempt has been made to indicate the effect of stress level on each grade by showing the lowest stress at which two out of three test samples did not fracture in 1000 hours or more. This figure is approximate but shows some striking differences in the various alloys.

The direct tension test produced failures in shorter times and at lower hardness levels than the horseshoe test. This difference has been observed often, commonly in past stress corrosion cracking tests comparing fixed load and fixed deflection stressing. In the latter, or horseshoe type test, the first appearance of a crack in the specimen tends to lower the overall stress and lessens the severity of the test, while the reverse is true in the direct tension test.

The 9 percent Ni steel sample failed extremely rapidly at 100,000 psi and even cracked quickly at loads less than 35 percent of the yield strength. Others have found this alloy is very susceptible to failure in acidic hydrogen sulfide. N80, J55 and 4340 steels also failed rapidly at 100,000 psi but were appreciably better than 9 percent Ni at the 50,000 psi stress level. The J55 alloy is a relatively soft material but cracked when stressed within 95 percent of its yield strength.

Type 410 cracked at relatively low stress levels (about 35 percent of its yield strength) when hardened to Rockwell C40. Tempered to lower hardness levels, it was significantly improved. At a hardness of C32 it appeared slightly better than N80 or 4340. Past reports[4] have suggested that this alloy is an unusually susceptible material but this is not borne out if the comparison is made with other steels heat treated to the same hardness.

Armco 17-4 PH, 17-7 PH and Type 422, each treated to Rockwell C30 or slightly higher, have been more resistant to cracking than the other materials and appear able to resist cracking at stress levels approaching 90,000 psi, or up to about 70 percent of their yield strength.

Ability of these alloys to resist cracking at higher hardness levels than other hardenable steels may be attributed to the fact that their strength is derived by precipitation processes. They may be tempered at much higher temperatures than the other alloys without losing hardness. Susceptibility to corrosion cracking in hardenable alloys seems to be associated with fully martensitic structures. When these are sufficiently tempered to ferrite and carbide structures crack susceptibility is diminished. It is noteworthy that the ferritic stainless steels have several times been found immune to stress corrosion cracking in media which will readily crack austenitic stainless steels. Tempering at high temperatures also has the benefit of relaxing internal stresses. It has been shown[9] that even low alloy steels require heating to 1000 F to relax internal stresses to less than 50 percent of their initial value.

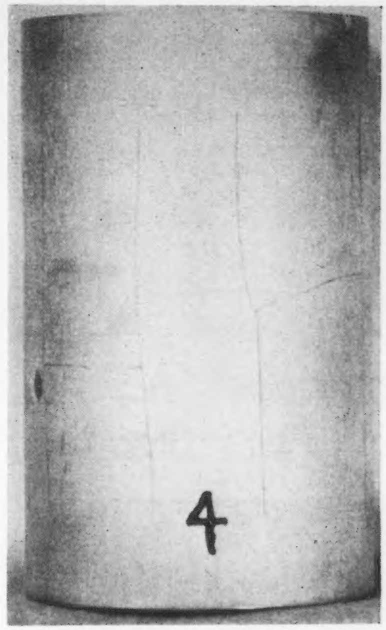


Figure 8—Type 410 hardened from 1800 F, quenched in oil at room temperature and tempered at 600 F. Cracked from internal quenching stresses when exposed to ½% HAc—6% NaCl-H_2S solution.

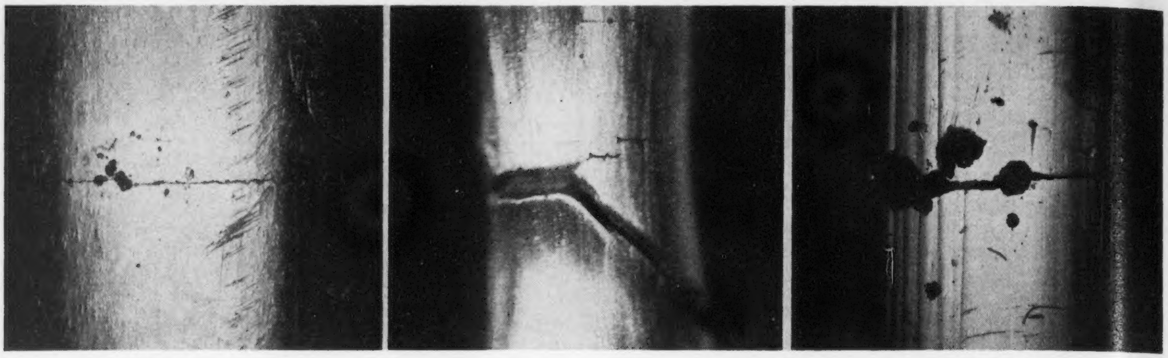
It has been suggested[10] that the extreme susceptibility of the 9 percent Ni steels to cracking, even after tempering to moderate hardness levels is due to the tendency of this alloy to retain networks of untempered martensite.

D. *Effect of Internal Quenching Stresses*

Early tests showed that specimens, oil quenched from the hardening temperature would crack in the acetic acid-hydrogen sulfide-sodium chloride media even though not externally stressed. Cracking of this type as the result of internal quenching stresses is probably as significant in most applications as cracking under external loads. A series of tests was conducted to compare the susceptibility of several grades to stress corrosion cracking from quenching strains alone and to briefly explore the possibilities of mitigating them by martempering. One set of cylindrical samples was hardened by quenching directly into an oil bath at room temperature. A second set was martempered by quenching from the hardening temperature into a salt bath at 600 F, holding for twenty

TABLE 8

Grade	Heat No.	Sample Size, Inches	Hardening Temp. Degrees F	Quench	Rockwell Hardness C	Appearance After Exposure to ½%HAc-6%NaCl-H_2S
410	23734 23734	¼θx2 ¼θx2	1800 1800	Oil—R.T. Salt—600 F	42–43 39–40	Cracked OK
410	34126 34126	2θx2 2θx2	1800 1800	Oil—R.T. Salt—600 F	46–47 43–43	Cracked OK
431	22694 22694	¼θx2 ¼θx2	1800 1800	Oil—R.T. Salt—600 F	43–44 43–44	Cracked OK
440A	42101 42101	¼x2 ¼x2	1900 1900	Oil—R.T. Salt—600 F	50–51 48–48	OK OK

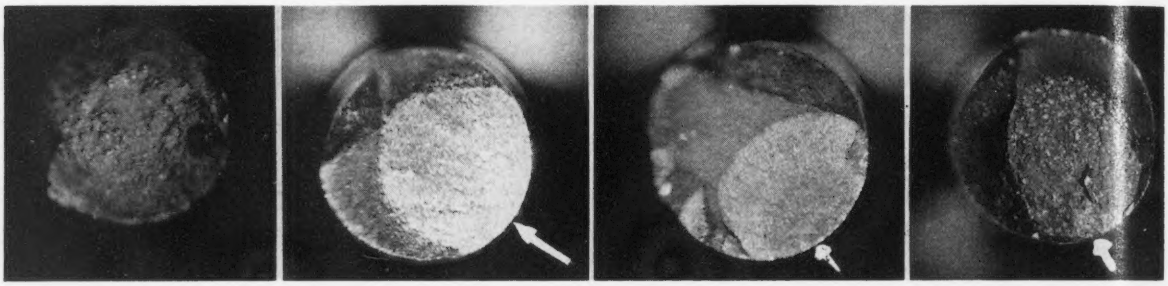


a. Type 440C horseshoe sample exposed at Harbor Island. X5

b. Type 410 tension test fractured in ½% HAc plus H_2S. X5

c. Type 420 horseshoe sample fractured in ½% HAc plus H_2S. X5

Figure 9—Surface appearance of various test samples showing cracks developing from corrosion pits.



a. Type 410—Normal tensile fracture.

b. Type 410—Stress corrosion fracture. 75 hr., 100,000 psi.

c. 17-4 PH—Stress corrosion fracture. 556 hr., 100,000 psi.

d. SAE 4340—Stress corrosion fracture. 13 hr., 100,000 psi.

Figure 10—Appearance of fractured ends of tensile type samples. Sample a was broken in a tensile machine and represents a normal cup and cone fracture where no corrosion cracking is present. Samples b, c and d are stress corrosion failures in ½% HAc+ H_2S. Arrows indicate point at surface where initial pit occurred. All photographs X 10.

minutes, then cooling in air to room temperature. Both were then stress-relieved at 600 F for four hours. After careful descaling in non-acid media they were exposed to the severe ½% acetic acid-6% sodium chloride solution saturated with hydrogen sulfide for seven to ten days and examined. Figure 8 illustrates the appearance of cracks developed in this test. The results of these tests are summarized in Table 8.

This particular series showed clearly the benefit of martempering. The lesser susceptibility of Type 440A to corrosion cracking when quenched in oil at room temperature is interesting. Earlier work has shown that the very high-carbon grades are less likely either to quench crack or crack on acid pickling than the medium-carbon grades. This may be due to larger amounts of retained austenite in the hardened material but further work would be required to verify this. The observation may have practical significance in applications such as valve seats and balls for use in sour oil service where the potentiality of stress corrosion cracking exists and where quenching is the source of stress.

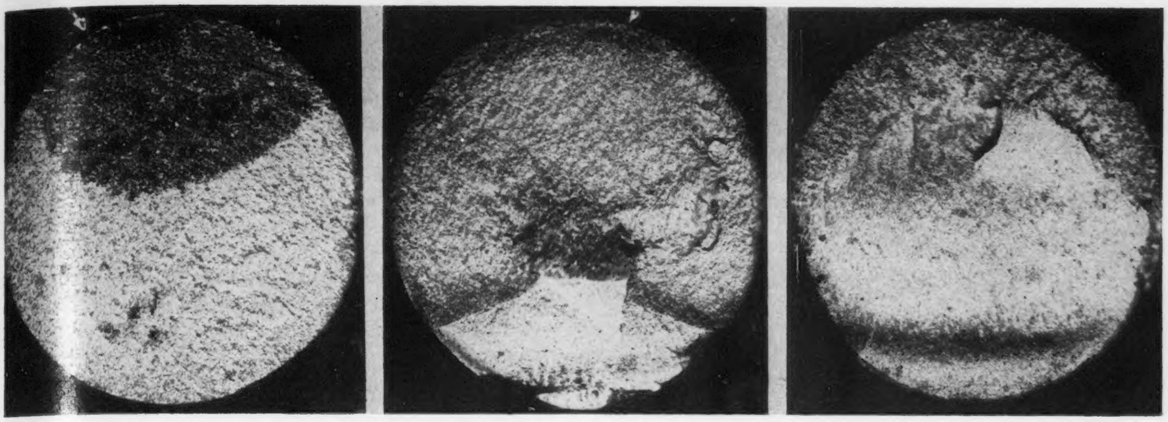
A few tests were conducted to determine how high a tempering temperature was required to relieve quenching stresses enough to avoid cracking. Types 410 and 431 samples ¼-inch in diameter by 2 inches were quenched from 1800 F into oil at room temperature, then drawn at various temperatures from 600 to 1200 F. After descaling in non-acid media they were exposed for ten days at room temperature in ½% acetic acid-6% sodium chloride solution saturated with H_2S. The results are summarized in Table 9.

Cracking in Type 410 was prevented by tempering at 1050 F and above, while in Type 431 tempering at 950 F was adequate. This variation is probably due to differences in the initial level of quenching stress and perhaps to the presence of retained austenite which is larger in Type 431. The General Electric Company has reported that stress-relieving Type 410 at 950 F was adequate to prevent cracking in compressor blading tested in their hydrochloric acid-selenium oxide media.

It seems likely that the maximum safe tempering temperature to avoid stress corrosion cracking of Type 410 will depend on the severity of the quench and the nature of the corroding media. For the most severe conditions, tempering should be carried out at 1050 F or higher unless steps such as martempering are employed to minimize quenching stresses.

E. *Appearance of Stress Corrosion Cracks*

While this investigation was concerned primarily



a. 17-7 Ph cracked at Harbor Island. 120 days, 100,000 psi.

b. Type 431 cracked in ½% HAc—H_2S. 7 days, 100,000 psi.

c. Type 420 charged with hydrogen cathodically. 2 hours, 100,000 psi.

Figure 11—Appearance of fractured ends of horseshoe type samples. Samples a and b failed by stress corrosion cracking. Arrows indicate location of the initial pit. Sample c was fractured by charging with hydrogen. Magnification of all photographs slightly less than 10.

with a study of the effects of composition and heat treatment on susceptibility to cracking, several observations of interest were made of the mechanism leading to the cracking and spontaneous failure of the hardenable stainless grades. The fractured samples were examined under binocular microscopes at moderate magnifications. A number of cracked samples were sectioned and examined at high magnification to establish the course of cracks through the grain structure.

Figure 9 a, b and c illustrate one point of interest, namely, that the cracks in many cases and perhaps in all instances, initiate from pits. In all test media and when specimens could be found which, in addition to the main fracture, possessed other finer cracks, these could generally be associated with a tiny corrosion pit. They were sometimes difficult to identify because the pit was not much wider than the crack.

Examination of the ends of fractured samples of both horseshoe and tension samples indicated that after the pit formed a crack spread out from it fanwise through the sample until the cross-section was substantially reduced, at which point it then fractured abruptly. In the tension samples the semicircular area surrounding the initial pit was flat, granular, brittle in appearance and at right angles to the surface. In some instances it was stained with what appeared to be a corrosion product. The balance of the fracture area was smoother, usually occurring about 45 degrees to the surface, similar in appearance to the cone section of a normal tension fracture and gave evidence of some ductility in a slight necking-down of the sample where this portion of the crack met the surface. (See Figure 9b.) Typical examples of fractured tensile type samples are shown in Figure 10 a, b, c and d.

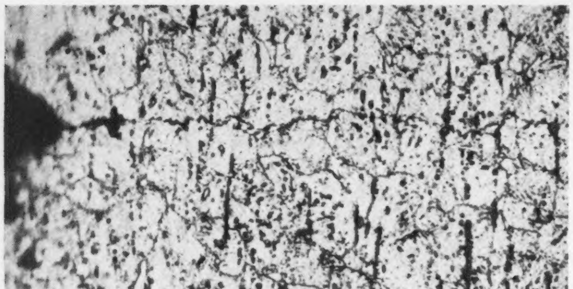
In the horseshoe sample a similar situation occurred except that the corrosion crack initiating at a pit would progress in most cases almost across the whole cross-section of the sample before it finally fractured. Figure 11 a and b are good examples of this.

Figure 11c illustrates the appearance of the fractured end of a Type 420 horseshoe specimen, hardened and tempered at 600 F, which was stressed to 100,000 psi. It was charged cathodically at 0.04 amperes/square inch with hydrogen from a solution of 10 percent sodium hydroxide and fractured after two hours. There was no evidence of any corrosion on the sample.

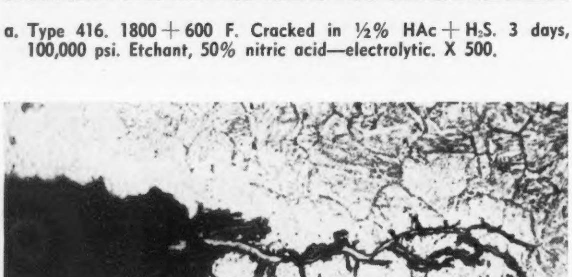
The rough textured crescent-shaped area at the top of the specimen in Figure 11 c represents an initial crack which developed under the combined action of stress and hydrogen cathodically introduced into the sample. The smoother, brighter area under it was formed when the sample fractured spontaneously. The rough surface of the original crack is very similar in appearance to the stress corrosion cracked areas in Figure 11a and b and offers support to the theory that hydrogen is a factor in the development of stress corrosion cracks in hardened steels.

Attempts to determine whether the stress corrosion cracks were intergranular or transgranular were handicapped by the difficulty of etching the samples in a manner that would clearly delineate the grain boundaries. Two typical photomicrographs are shown in Figure 12 a and b. It was concluded from examination of these and many other samples that cracking was both through and around the grains but was predominantly transgranular. The cracks were markedly different in appearance from stress corrosion cracks in austenitic stainless steels in that they showed less branching as can be seen by comparison with Figure 12 c. This latter shows the appearance of the cracks that developed in the austenitic Armco 17-10 P alloy exposed to the ½% acetic acid-6% NaCl-hydrogen sulfide solution.

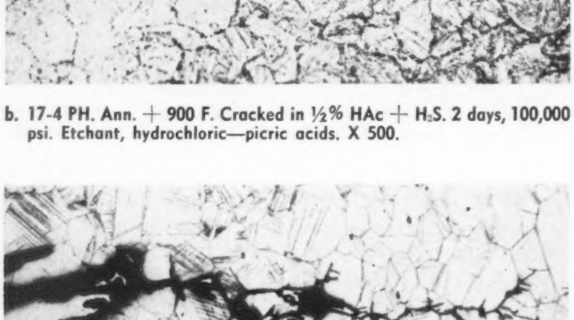
The mechanism of stress corrosion cracking in hardenable steels has been the subject of considerable speculation. Some investigators have suggested that the cracks are caused solely by internal hydrogen stressing from atomic hydrogen diffusing into the metal during corrosion, precipitating at internal



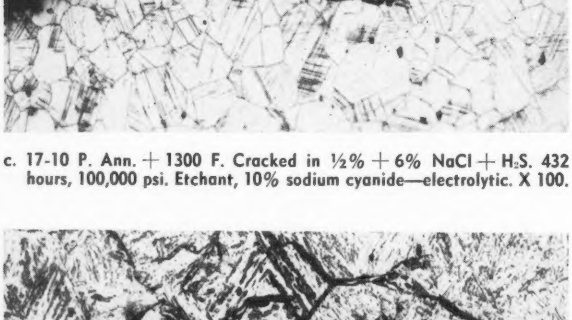
a. Type 416. 1800 + 600 F. Cracked in ½% HAc + H_2S. 3 days, 100,000 psi. Etchant, 50% nitric acid—electrolytic. X 500.



b. 17-4 PH. Ann. + 900 F. Cracked in ½% HAc + H_2S. 2 days, 100,000 psi. Etchant, hydrochloric—picric acids. X 500.



c. 17-10 P. Ann. + 1300 F. Cracked in ½% + 6% NaCl + H_2S. 432 hours, 100,000 psi. Etchant, 10% sodium cyanide—electrolytic. X 100.



d. Type 410. 1900 + 600 F. Cracked cathodicaly in 10% sodium hydroxide at 0.04 amperes. sq. in. 2 hours, 100,000 psi. Etchant, HCl-picric. X 250.

Figure 12—Microstructure of various grades showing appearance of stress corrosion cracks.

lattice dislocations and developing sufficient pressure to exceed the rupture strength of the metal. Others have suggested that he cracks are produced by the mechanism proposed by Mears, Brown and Dix[11] which attributes their formation to the presence of preferred localized paths for corrosion, tensile stresses which keep these initial cracks open and electrochemical action between anodic metal at the crack bottom and the balance of the material, which accelerates corrosion. Fraser and Treseder[8] have proposed a combined mechanism which involves normal stress corrosion accelerated by hydrogen precipitated in deformed metal just ahead of the crack.

Observations of the Armco Laboratories are best explained by the latter viewpoint. The apparent origin of the cracks from pits suggests that the initiation of the crack is through a normal corrosion mechanism. The fan-like spread of the cracks from the pit locus might be attributed to hydrogen embrittlement of the surrounding metal. The presence of corrosion products on the crack surface, however, suggests that corrosion continues beyond the pit. On the other hand, the fact that Type 420 samples could be cracked under stress by cathodically introduced hydrogen in the complete absence of corrosion shows that hydrogen of itself can promote cracking very similar in appearance to stress corrosion cracks. Figure 12 d shows that cracking from hydrogen also is predominantly transgranular and proceeds through the structure in a manner identical with stress corrosion cracking.

Summary

1. Martensitic hardenable stainless steels are susceptible to cracking under the combined influence of corrosion and tension stress either externally applied or present as internal residual stresses from quenching. Such cracking is apparently common to all high-strength hardened alloys. The likelihood of cracking is dependent on the kind of corrosive medium, the hardness of the material, heat treatment, the level of applied stress and the type of alloy.
2. The most severe media appear to be those which promote hydrogen embrittlement, such as acid-sulfide solutions and which contain chlorides that promote corrosion pitting. In the acetic acid-hydrogen sulfide test cracking occurred at hardness levels as low as Rockwell C24; in severe marine atmospheres at C40 and above; and in severe industrial atmospheres at C45. Salt fog and aqueous salt solutions caused cracking at Rockwell C45 and higher.

TABLE 9

Tempering Temp. Degrees F.	RESULTS OF CRACKING TEST			
	TYPE 410		TYPE 431	
	Rockwell Hardness	Appearance	Rockwell Hardness	Appearance
600	C40-41	Severe cracks	C43-43	Few cracks
800	C40-41	Severe cracks	C43-43	Moder. cracks
950	C40-40	Moder. cracks	C34-34	OK
1000	C35-36	Few cracks	C32-33	OK
1050	C29-29	OK	C28-29	OK
1100	C24-24	OK	C27-27	OK
1150	C21-21	OK	C25-26	OK
1200	B98-98	OK	C23-24	OK

3. The precipitation-hardening alloys, 17-4 PH and 17-7 PH, were susceptible to stress corrosion cracking if aged to their maximum hardness but were among the most resistant materials if overaged. For exposure to severe industrial or marine atmospheres under high stresses the usual recommended overaging temperature of 1050 F is satisfactory to provide immunity to stress corrosion cracking with 17-7 PH. For similar exposure 17-4 PH should be overaged at 950 to 1000 F. For service in extremely severe conditions, such as represented by the acid-hydrogen sulfide test, both alloys look promising when overaged at 1150 F to a hardness of about Rockwell C30. Type 422, the modified 12 percent chromium alloy, also has shown excellent performance in similar media when tempered to the same hardness level.

4. Severely cold worked austenitic alloys, Types 304 and 305, cracked only in the acid-hydrogen sulfide medium containing sodium chloride. This was also true of 17-10 P precipitation-hardened to Rockwell C30. Cracks which developed in these alloys had the typical transgranular branched appearance and seemed to be of a different character from those in the hardenable steels. No difference was noted between the Types 304 and 305, although one was strongly magnetic after cold work and the other was not.

5. Internal stresses generated in quench hardening can be sufficiently high to promote stress corrosion cracking in the hardenable grades. Some limited work suggests that interrupted quenching (martempering) is helpful in avoiding this. Tempering at 1000 to 1050 F reduced internal stresses in oil quenched Type 410 to a level low enough to prevent cracking in the severest media used.

6. It appears likely that stress corrosion cracking in hardened stainless steels is accelerated by hydrogen generated by corrosion and absorbed in the steel. The cracks initiate in many instances from pits developed on the surface of the specimen and are primarily, but not exclusively, transgranular. They are similar in appearance to those produced by cathodically introduced hydrogen.

Conclusions

Where the hardenable stainless steels, like other hardened alloys, are exposed under stress to certain types of corrosive media the possibilities of stress corrosion cracking must be considered. The greatest likelihood of such cracking is in acid environments containing elements which promote hydrogen embrittlement, such as compounds of sulfur and selenium. Cracking is induced also by the presence of chlorides.

In the very severe media used to judge the suitability of materials for sour gas condensate well service Types 410, 416 and 431 performed as well as or somewhat better than lower alloy steels at equal hardness levels. These grades should continue to be considered for service where the existence of acids and dissolved carbon dioxide creates corrosive conditions too severe for low alloy steels. Tempering at 1100 F or higher should provide good resistance to cracking under high stress levels. Where higher strength and hardness are required Type 422, 17-4 PH, and 17-7 PH should be attractive for well head fittings, bolts, valves and the like.

In aircraft structures exposed to marine atmospheres Types 410 and 431 as well as precipitation-hardening alloys, particularly in the overaged condition, look attractive. Both of the precipitation-hardening alloys have been in such service now for several years and have never been reported as failing from stress corrosion cracking. Their use in food conveyor chains is currently being investigated and so far the results appear very encouraging.

When the hardenable stainless grades are to be used fully hardened for valve trim and other applications where externally applied service stresses are low but where corrosive conditions indicate the possibility of stress corrosion cracking, the use of martempering procedures to minimize heat treating stresses should be considered.

Acknowledgment

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Any discussions of this article not published above will appear in the December, 1955 issue.

An Educational Lecture

The Electrochemistry of Inhibitor Action*

By R. B. MEARS*

Introduction

IT HAS NOW BEEN established that aqueous corrosion is electrochemical in nature. That is, it is associated with the flow of electric currents over finite distances.

The basic driving force for the corrosion reaction is the reversible potential between the metal and its corrosion product. This is related to the free energy of formation of the corrosion product by the following equation:

$$\Delta \phi = n\,F\,E_r \qquad (1$$

Where:

$\Delta\phi$ equals the free energy of formation of the corrosion product in gram calories.
F is a constant equal to 23,066.
E_r is the reversible potential.
n is the number of equivalents that react.

For example, when iron corrodes in water in the presence of oxygen at 0.21 atmosphere pressure to form ferric hydroxide according to the following chemical equation:

$$2\,Fe + 3H_2O + 3/2\,O_2 \rightleftarrows 2\,Fe\,(OH)_3$$

$$\Delta\phi = -80{,}000 \text{ gram calories per gram atom of iron}$$

$$\text{then } E_r = \frac{80{,}000}{3 \times 23{,}066} = 1.15 \text{ volts}$$

The reversible potential (E_r) is the driving force for the corrosion reaction. This driving force is the same for all cases of corrosion of iron at normal conditions of temperature and pressure, provided only that the ultimate corrosion product is $Fe\,(OH)_3$.

In the corrosion circuit at steady state conditions, as in any electrical circuit, the driving force (E_r) must equal the dissipative forces. These dissipative forces include the IR drops through the metallic and liquid paths and the special irreversible effects adjacent to the electrode surfaces.

For convenience, these surface irreversible effects can be grouped together and termed "electrode polarization." Under steady state conditions, we may then write:

$$E_r = E_a + E_c + E_R + E'_R \qquad (2$$

where

E_r = the reversible potential
E_a = the anode polarization
E_c = the cathode polarization
E_R = IR = the corrosion current multiplied by the resistance of the electrolyte between the anode and cathode areas
E'_R = IR′ = the corrosion current multiplied by the resistance of the metallic path between the anode and the cathode

Abstract

Principles involved in the electrochemistry of inhibitor action are discussed. Electrical terms are used to explain the inhibiting action of substances and to show what properties are desirable in an inhibitor. The mechanism by which sodium chromate and sodium hexametaphosphate function as inhibitors is discussed in detail.

In most corrosion cells, E'_R is very small and can be neglected. In contrast, E_a and especially E_c are so large that they completely outweigh E_R in importance under many common conditions of corrosion. Both E_a and E_c are complex quantities. Generally they are made up, in part, of an IR drop through a film or layer on the electrode surface and, in part, of a back emf caused by gas overvoltage or concentration polarization.

Equation (2 then can be rewritten as follows:

$$E_r = (E'_a + IR_a) + (E'_c + IR_c) + IR_e \qquad (3$$

where

E'_a = back emf at the anode
E'_c = back emf at the cathode
R_a = resistance at the anode surface
R_c = resistance at the cathode surface
R_e = resistance through the electrolyte

On rearranging, Equation (3 becomes

$$I = \frac{E_r - (E'_a + E'_c)}{R_a + R_c + R_e} \qquad (4$$

In other words, the corrosion current (I) is a function of the reversible potential for the corrosion reaction (E_r), the back emf's at the local anode and cathode (E'_a and E'_c), the resistances of the electrolyte and of the anode and cathode films (R_a, R_c and R_e), and of nothing else.

Desirable Inhibitor Properties

By definition, an inhibitor is a substance that reduces the corrosion current, (I). Therefore, the only possible desirable properties of an inhibitor are to:

1. Change the nature of the corrosion product that is formed (that is, to reduce E_r).
2. Change the back emf's at the surfaces of the anode or cathode (that is, to increase E'_a or E'_c).
3. Change the resistance of the electrolyte, or of the anode or cathode films (that is, to increase R_a, R_c, or R_e).

In other words, to "explain" the inhibiting action of any substance, no progress is made by establishing that the inhibitor forms a film of a specific composition or crystal structure. The effect of the inhibitor must be expressed first in electrical terms.

* An educational lecture presented at a meeting of Northeast Region, National Association of Corrosion Engineers, New York, N. Y., May 9-11, 1955.

* Manager Applied Research Laboratory, United States Steel Corp., Monroeville, Pa.

Otherwise, progress in understanding the mechanism of inhibitor action is impossible.

So far, only the theoretical aspects of the corrosion cell have been considered. Consider now the more practical aspects.

Theoretically, the driving force for the corrosion reaction is E_r. However, under experimental conditions when attempts are made to measure the difference in potential between local anodes and local cathodes of a corrosion cell at "zero" current, a smaller value (E_o) is obtained. This "open circuit" potential is generally much smaller than E_r.

The reason that E_o and E_r do not agree in magnitude must be that, under the experimental "open-circuit" conditions, a small current is still flowing between local areas on the anode or cathode. These currents must be very small because they are insufficient to cause an appreciable discrepancy when the measured currents are correlated with corrosion losses.

Evidently, very small currents flowing between local areas on the anode (or on the cathode) can cause a substantial shift in its potential.

Experimentally, therefore, Equation (4 becomes

$$I = \frac{E_o - (E'_a + E'_c)}{R_a + R_c + R_e} \qquad (5$$

where E_o is the "open-circuit" potential between the local anodes and the local cathodes. E_o is always smaller than E_r and is usually much smaller.

Although under experimental conditions it is possible to measure the IR drops through surface films on the anode and cathode, it is simpler to measure the overall irreversible effects at the electrode surfaces, that is, to measure E_a and E_c.

Thus, Equation (5 then becomes

$$I = \frac{E_o - (E_a + E_c)}{R_e} \qquad (6$$

Mechanism of Sodium Chromate as an Inhibitor

In a few cases, the mechanism of inhibitors has been studied in terms of Equation (6. One such study has been described by Mears and Brown[1] and relates to the behavior of chromates as corrosion inhibitors for aluminum.

By the use of a technique that was described in an earlier paper,[2] it was possible to measure the various quantities of Equation (6 directly for the case of aluminum corroding in a 10 percent sodium chloride solution to which various amounts of the inhibitor, potassium chromate, were added.

The results of these studies are summarized in Figure 1. It can be seen that potassium chromate acts as a corrosion inhibitor because it 1) reduces the "open-circuit" potential difference between the local anodes and cathodes, and 2) increases the polarization of the local anodes. It would be an even more effective inhibitor if it did not also *decrease* the polarization of the local cathodes.

To express this quantitatively in terms of Equation (6, consider the case of aluminum corroding in

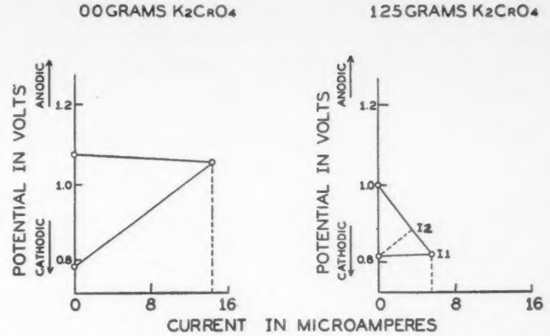

Figure 1—Effect of concentration of chromate on local cells on aluminum in 10 percent sodium chloride solution.

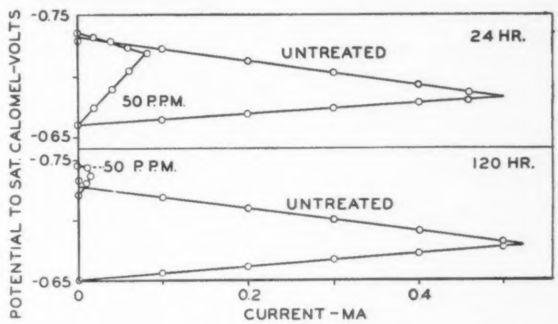

Figure 2—Influence of sodium hexametaphosphate on polarization of steel electrodes of a differential aeration cell (from Hatch's data).

an uninhibited 10 percent sodium chloride solution:

$I = 14.5$ microamps
$E_o = 0.4$ volt
$E_a = 0.11$ volt
$E_c = 0.29$ volt
R_e is substantially zero

When 1.25 grams of potassium chromate are added to the above solution, the values become

$I = 6.7$ microamps
$E_o = 0.19$ volt
$E_a = 0.18$ volt
$E_c = 0.01$ volt
R_e is substantially zero

Mechanism of Sodium Hexametaphosphate as an Inhibitor

Hatch[3] has studied the mechanism of the inhibiting action of sodium hexametaphosphate. His results are illustrated in Figure 2. In this case, the inhibiting action increased with the passage of time. If the terms of Equation (6 are evaluated using Hatch's data for both 24 and 120 hours, the results are as follows in Table 1:

TABLE 1—Sodium Hexametaphosphate as an Inhibitor

	NO INHIBITOR		SODIUM HEXAMETAPHOSPHATE 50 ppm	
	24 Hours	120 Hours	24 Hours	120 Hours
I	0.50 ma	0.52 ma	0.08 ma	0.01 ma
E_o	0.08 v	0.08 v	0.08 v	0.02 v
E_a	0.06 v	0.05 v	0.01 v	0.005 v
E_c	0.02 v	0.03 v	0.07 v	0.015 v
R_e	Nil	Nil	Nil	Nil

It will be noted that the short-range (24 hours) effect of the sodium hexametaphosphate is to increase the cathodic polarization. After a longer period of time (120 hours), the slope of the cathodic polarization curve has not altered much from the 24-hour value. The open circuit potential difference (E_o) however, has decreased greatly and this change is now accounting for much of the inhibiting action.

Use of Electrochemical Measurements in Studying Other Inhibitors

It seems probable that an electrochemical approach would throw much light on the behavior of other inhibitors. If data of this type were obtained on numerous inhibitors, it seems probable that they could be grouped into various categories. Some classes of inhibiting materials would affect anodic or cathodic polarization, while others would affect the "open circuit" potential difference. Knowing the electrochemical behavior of these different classes of materials, it would be possible then to predict the behavior of potentially inhibitive chemicals.

References

1. R. B. Mears and R. H. Brown. *Jl. Electrochem. Soc.*, **97**, 75, (1950).
2. G. G. Eldredge and R. B. Mears. *Ind. Eng. Chem.*, **37**, 738, (1945).
3. G. B. Hatch. *Ind. & Eng. Chem.*, **44**, 1779, (1952).

Any discussions of this article not published above will appear in the December, 1955 issue.

DISCUSSIONS ON TECHNICAL ARTICLES ARE SOLICITED

Discussions on technical articles published in Corrosion will be accepted for review without invitation. Discussions must be constructive, accompanied by full substantiation of fact in the form of tables, graphs or other representative data and be submitted in three typewritten copies.

Authors of discussions are asked to supply one copy of figures suitable for reproduction and will be sent on request a copy of the NACE Outline for the Preparation and Presentation of Papers.

Discussions will be reviewed by the editor of Corrosion and will be sent to the author of the paper discussed for his replies, if any. Publication will be in the Technical Section with full credit to the authors together with replies. Discussions to papers presented at meetings of the association may be submitted in writing at the time of presentation or later by mail to the editorial offices of Corrosion, 1061 M & M Bldg., Houston 2, Texas.

Technical Committee Activities

Condensate Well Control Practices Summarized

T-2 Officials Experienced In Corrosion Work

Stewart

Sudrabin

In March, 1954, with the re-organization of the Technical Committees, Group Committee T-2 on pipe line corrosion was formed and W. H. Stewart, Sun Pipe Line Company, was appointed chairman. A letter ballot vote was taken and L. P. Sudrabin, Electro Rust-Proofing Corporation, Newark, New Jersey, was elected vice-chairman of the group.

W. H. "Bill" Stewart has been in corrosion work since 1934. Mr. Stewart was born in 1904 at Comanche, Texas, attended grade school in San Antonio, Texas and high school at Comanche. In 1916, Bill became interested in radio, called wireless in those days. He became a licensed "ham" operator in 1916. In 1923 through 1927 he constructed custom made radios. In 1928 Bill joined the Interstate Geophysical Company and in 1939 became affiliated with the Sun Oil Company Electro Geophysical Laboratory. In 1934 he was loaned to the Sun Pipe Line Company for a 90-day corrosion study and is still studying.

Bill has been a member of NACE since 1944. He is, in addition to being chairman of Group Committee T-2, a member of NACE's board of directors, chairman of the National Gasoline Association of America's Condensate Well Corrosion Committee 1948-49, a member of API, external pipe line corrosion subcommittee and a member of several T-1 and T-2 Technical Unit Committees.

L. P. Sudrabin is Director of Engineering Services and Development of the Electro Rust-Proofing Corporation. He graduated from Northeastern University in 1936 with a BS in Chemical Engineering. From 1936 to 1943 he was chief chemical engineer for the Dayton Power & Light Company. In 1943 and 1944 he served as a research engineer with the Dorr Company, Westport, Connecticut, developing cathodic protection principles and has been with the Electro Rust-Proofing Corporation since 1944. In addition to holding the office of vice-chairman of Group Committee T-2, Mr. Sudrabin is chairman of Unit Committee T-2C on Minimum Current Requirement for Cathodic Protection. He has been a member of NACE since 1944, he is a member of the Electrochemical Society, the NSPE, the AIChE, the AWWA and is a registered professional engineer in the states of New Jersey and Ohio.

Committees Invited To These Sessions

South Central Region: October 18-21, 1955, Shamrock Hotel, Houston, Texas. October 18 and 19 being reserved for Technical Committee meetings. To reserve meeting space notify: T. J. Hull, NACE, 1061 M & M Bldg., Houston.

Northeast Region Meeting: October 31-Nov. 3, 1955, Niagara Falls, New York. October 31 being reserved for Technical Committee meetings. To reserve meeting space notify: T. J. Hull, 1061 M & M Bldg., Houston.

Western Region Meeting: November 17 and 18, 1955, Sir Francis Drake Hotel, San Francisco, California. To reserve meeting space notify: T. J. Hull, 1061 M & M Bldg., Houston.

TENTATIVE SCHEDULE
SOUTH CENTRAL REGIONAL MEETING

Houston, Texas, October 18, 19, 20, 21, 1955

Committee

T-1	Corrosion in Oil and Gas Well Equipment. All Day Tuesday
T-1C	Sweet Oil Well Corrosion. 1:30 P.M. Wednesday
T-1D	Sour Oil Well Corrosion. 8:30 A.M. Wednesday
T-1D-1	Fundamentals of Corrosion. 9:00 A.M. Thursday
T-1H	Oil String Casing Corrosion, 10:00 A.M. Wednesday
T-1J	Oil Field Structural Plastics. 9:00 A.M. Thursday
T-1K	Inhibitors for Oil and Gas Wells. 1:30 P.M. Wednesday
T-2A-2	Ribbon Anodes. 9:00 A.M. Tuesday
T-2B	Anodes for Impressed Currents. 1:30 P.M. Tuesday
T-2C	Minimum Current Requirements for Cathodic Protection. 9:00 A.M. Wednesday
T-2D	Standardization of Procedures for Measuring Pipe Coating Leakage Conductance. 1:30 P.M. Wednesday
T-2E	Internal Corrosion of Product Pipe Lines and Tanks. 9:00 A.M. Wednesday
T-2J	Wrappers for Underground Pipe Line Coating. 1:30 P.M. Tuesday
T-2K	Prefabricated Plastic Film for Pipe Line Coating. 1:30 P.M. Wednesday
T-3B	Identification of Corrosion Products. 1:30 P.M. Tuesday
T-4F-1	Water Meter Corrosion. 1:30 P.M. Tuesday
T-5B-2	Sulfide Corrosion at High Temperatures and Pressures in the Petroleum Industry. 9:30 A.M. Wednesday
T-5C-1	Corrosion by Cooling Waters, South Central Region. 1:30 P.M. Wednesday
T-6A	Organic Coatings and Linings for Resistance to Chemical Corrosion. 9:00 A.M. Tuesday
T-6B	Protective Coatings for Resistance to Atmospheric Corrosion. 9:00 A.M. Wednesday
T-6E	Protective Coatings in Petroleum Production. 9:00 A.M. Thursday

Several Criteria Used To Rate Merits of Corrosion Inhibitors

Unit Committee T-1B on Condensate Well Corrosion has reported to Group Committee T-1 that a summary of replies received from a questionnaire designed to ascertain current practices used to control corrosion in condensate wells has been completed. Replies indicate that most operators use iron content of produced water to classify condensate wells as to severity of corrosion. If the iron content is 50 parts per million or less, the well is classified as non-corrosive and if it is more than 50 parts per million, it is usually classified as corrosive. During the first two or three months of the well's life, produced iron content is erratic and probably means little. This is also true of wells that have been worked over or wells that have started to produce salt water.

Some operators determine the carbon dioxide content of gas and use either its concentration of partial pressure as a criterion.

Internal tubing caliper surveys are widely used to determine the location, extent and severity of corrosion. Frequency of surveys depends upon the individual problem.

Treatments Rated by Same Gauges

By the combined use of iron content of the produced water, caliper surveys, carbon dioxide content and occasional coupon tests, wells are classified. The same criteria are used to determine if chemical treatments are successful. Relatively few operators attempt to very exactly classify individual wells according to severity of corrosion. Principally classifications are made to determine if a well should be treated. If several wells in a field are classified as corrosive, it is general practice that all wells in the field are classified as corrosive. Guided by experience in the area field or formation most operators now consider condensate wells corrosive unless proved otherwise.

The summary indicates relatively few condensate wells are completed without tubing packers. Wells without tubing packers usually are those that have shut-in tubing pressures of 2000 psi or less. However, one operator reported having some wells with pressures as high as 4000 lb. that are not equipped with packers.

Hollow Sucker Rods Considered

Only one operator had attempted to use chemical injection valves in tubing strings arranged so as to inject chemical via the casing. The necessity of carefully removing mud, loose mill scale and other materials from the casing is pointed out by those who have used these valves in oil wells. Water is used

(Continued on Page 54)

Several Criteria–

(Continued From Page 53)

by one operator to wash as much mud from the annulus as possible. This is followed by a 500 gallon hydrochloric acid treatment and more water and then by crude oil to try to clean the annulus before a valve is installed. New, special or unusual equipment reported in the questionnaire replies included one operator's plan to install hollow sucker rods as chemical injection strings and in wells producing substantial amounts of salt water. Experimental use of a "rabbit injector" was reported without detail except that it appears to operate effectively.

Fifty strings of 9 percent Ni tubing where chemical treatments are not used to protect the tubing string were reported in the summary of the questionnaire replies. Several replies indicated that minor pitting has occurred and all indicate that the iron content of the produced water is at about the same level as occurs when API steel tubing is used. A number of failures were reportedly caused by stress-corrosion cracking. In wells producing salt water, failures caused by pitting have been common. In most cases, chemical inhibitors are used to protect the flow lines from wells equipped with 9% Ni tubing.

One operator reported having three strings of 9% Cr tubing in service for a short time. Another operator reported on a mechanical failure that occurred when an attempt was made to pull 9% Cr tubing out of the hole immediately prior to the initial completion of the well. Cause of failure was not definitely determined.

5% Ni Tubing No Improvement

Except for one or two strings, all 5% Ni tubing is being treated with chemicals to prevent corrosion. It is the present consensus that this material is little better than API steels from a corrosion standpoint.

Insufficient information was reported on plastic coated tubing in wells where chemical treatments are not being used to truly evaluate the material. Several operators pointed out the coating failed adjacent to storm chokes or regulators installed in the tubing string and that mechanical damage of the coating on the pin end of the tubing had not been prevented. One operator reported having 21 strings of coated pipe in service that are currently being protected with corrosion inhibitors. These strings were installed in 1946 to 1948 and a conclusion was drawn that although failures no doubt have occurred in part of these strings, the coating paid for itself by protecting the tubing, at least partially, before the inhibitor program started.

Chemicals Preferred by Most

The majority of the replies to the question "Where do you think special tubing material should be used in preference to chemical treatment?" were that chemicals should be used in preference to special tubing materials. In the other replies it was pointed out that alloys possibly have an economic use in wells producing 10 MMcf per day in the case of fields that are expected to produce at high rates for 20 years or more in some off-shore wells and in some high fluid level wells where chemical treatments are difficult.

Five operators reported that no special materials were used in wellhead assemblies and wells that are chemically treated. Most other operators consider it good practice to use alloy adapter flanges and tubing master valves as special materials in chokes and choke assemblies. Materials that have been reported as being satisfactory in this service include: stainless steels Type 303, 410 or 410 modified and 416; Stellite, Monel, some copper base alloys and ceramic and carborundum chokes. Apparently there is no need to find or develop other special materials for use in wellhead assemblies or in-the-tubing assemblies.

Inorganic Chemicals Infrequently Used

The summary indicates that inorganic chemicals are used in only a few fields. In one area, two operators are treating wells by daily injection of water solutions of sodium bicarbonate in one case and sodium carbonate in the other. These treatments have been used for about four years and the results are good. There appears to be no special incentive to discontinue the use of these inorganic neutralizing agents.

One operator prefers the use of ammonia where low temperature separators are used because it has prevented troubles with emulsions and deposits in heat exchangers. Two operators are using chromates. One of these is in a field having 33 wells where the treatment makes the water from condensate wells compatible with other waste waters from the field and gas plant and permitting subsurface disposal of mixed waters from these sources without encountering sealing or corrosion problems in the disposal operations.

Stick Forms Helpful Sometimes

The use of organic inhibitors in stick form is generally limited to isolated wells or to cases where liquid chemical injections are considered impractical. More failures to obtain satisfactory results were reported when using stick inhibitors than when using liquid inhibitors. Some operators find that stick inhibitors can be applied in wells flowing at rates of less than 2 M Mcf per day without shutting in wells—an advantage in some fields. Wells treated with stick inhibitors generally are treated daily or twice a week, but sometime as infrequently as once a week.

Five different makes of liquid organic inhibitors are being used. The frequency of treating wells that have tubing set on packers varies considerably from daily treatments to monthly treatments. The majority of treatments are on a weekly or longer basis. When wells are treated daily or twice a week, it is the usual practice to dilute the inhibitor and keep the wells shut in for one or two hours. In the case of weekly or less frequent treatments, the trend is not to dilute the chemical and to keep the well shut in at least four hours.

Frequency Checks Are Made

One operator having a large number of wells in quite a few fields, has done considerable work to determine the frequency with which wells need to be treated. Beginning with the premise that treatments once every two or three weeks should be adequate if one quart of chemical is used per MMcf with gas and if the well is shut in long enough to give the chemical a chance to go to the bottom of the well, it has been prac-

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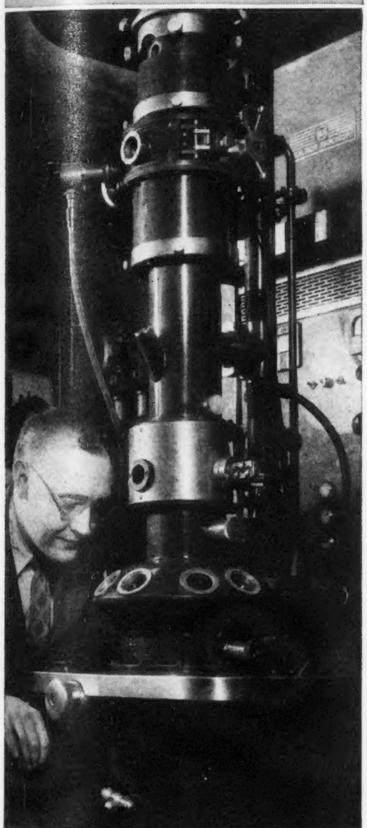

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The Control of Corrosion, Fouling and Product Contamination in Pipelines, Storage Tanks & Tankers

The corrosion problems of the petroleum industry may be roughly classified into three parts, namely, (a) production or oil well problems, (b) refinery problems dealing with process equipment and (c) corrosion problems of the transportation division, such as those occurring in pipelines, storage tanks and tankers. In this discussion we are considering only the corrosion problems associated with the transportation and storage of highly refined distillate products. For example, with gasoline or jet fuel the corrosion problem is usually one of rusting caused by moisture. The resultant peptized rust stabilizes an emulsion of minute particles of water fog causing a contaminated gasoline or an unsafe jet fuel.

Methods of proved merit for preventing this situation include (1) product dehydration, (2) the use of nitrite, chromate or other water-soluble rust preventives, (3) the addition of oil-soluble, film-forming, organic inhibitors, (4) the use of special alloy or plastic pipe and (5) interior plastic coatings or liners.

A substantial and significant amount of evidence from laboratory and field sources during the past year has confirmed the need for using oil-soluble corrosion inhibitors for the maximum protection of pipelines and tankers. The unique position of Unicor in this class of inhibitors is apparent to pipeline operators for the following important reasons:

Unicor prevents rusting in product pipelines at concentrations well below 10 ppm. Since it is distributed uniformly over the entire internal surface by the product itself, this protection is virtually 100% effective.

Unicor is slime-detergent and antifouling. No rusting can occur since Unicor's surface-activity causes a water-repellent film to be formed on the pipe's interior. This film sheds corrosive droplets.

Unicor is economical by virtue of (a) its low cost which is about 0.05c/bbl. of pipeline product, (b) the minute concentrations required and (c) its persistence in products from the refinery through the pipeline to the consumer, making re-inhibition unnecessary.

Water in a products pipeline is destructive. Its addition is unnecessary with Unicor. Unicor will also prevent rusting caused by unavoidably entrained or dissolved moisture.

Mechanical cleaning maintenance is materially reduced. The use of scrapers and the replacement of filters is reduced by over 50 per cent.

The beneficial effect of Unicor will extend to pipelines, storage tanks, tankers and ultimately even to consumer equipment when it is added within the refinery.

Addition at only one point is required since Unicor is distributed by the oil phase and is unaffected by water.

Unicor will not interfere with the action of other useful additives such as tetraethyl lead, antioxidants and dyes, and it has been especially prepared to avoid deleterious effects on gasoline stability.

Unicor has been formulated to meet the exacting water tolerance requirements of ASTM D910-53T as determined by ASTM D1094-53 in regard to entrainment of moisture and rust in hydrocarbon fuels. Unicor treated fuel rejects moisture.

Unicor is a non-irritating, nontoxic inhibitor; safe to handle and easy to apply.

Unicor is sold exclusively by Universal Oil Products Company. The technical services of petroleum specialists are available without charge to assist in the design, installation, and operation of a Unicor system of protection. For samples and information, write to Products Department, Universal Oil Products Company, 30 Algonquin Road, Des Plaines, Illinois.

Several Criteria–

(Continued From Page 54)

tical to set up schedules for effectively treating wells. In some fields, wells are produced continuously except when shut in for chemical treatment while in other fields individual wells are produced two or three weeks each month and are kept shut in the balance of the month. At least 10 gallons, but not more than 15 gallons, of undiluted chemical is used per treatment and, wherever possible, the well is kept shut in overnight after treatment. In general it is found that less than one quart of inhibitor per MMcf is necessary. One field after being treated with one quart per MMcf for about four months subsequently has been treated with one pint per MMcf without a resulting increase in iron content of produced water. A few wells have not responded to this method of treatment. In such cases several brands of chemicals have been tried if the frequency of treating has been required.

Diluents of chemicals include water, condensate Diesel fuel oil and kerosene. The diluent varies from 1:1 to as much as 1:4.

Cost Varies Widely

Cost of treating wells with organic inhibitors varies considerably and was reported to be from $300 to $2000 per well per year including labor and transportation. The average appeared to be about $600 to $700 per well per year, with high cost wells those in marine locations. The only undesirable side effects reported are that some inhibitors cause emulsification and others have caused deposits or thick layers in heat exchangers and other spots in the well and separator system.

Emulsification can be very serious in separators, especially where low temperature separators are used, by increasing the carry-over of liquids in the gas, and in the loss of liquid hydrocarbons with the water. In some instances emulsions greatly reduce the capacity of the separating vessels. Some organic inhibitors tend to break or suppress emulsions. One operator reported on preliminary work that indicates some of the organic inhibitors being used will reduce the pour point of condensates that congeal at relatively high temperatures.

Salt Water Has Adverse Effect

Salt water appears to reduce the effectiveness of inhibitors. Exact data were not reported but it is presumed that a loss of effectiveness becomes evident when the volume of water produced exceeds the amount of liquid hydrocarbons produced. There is no consensus in regard to the persistence of organic inhibitors. Those who have done the most experimenting indicate that for practical purposes inhibitors last for two to three weeks. Several reported they have evidenced they last much longer, up to as much as four months. It is evident that batch treatments once a week are effective in all but few wells and that in the majority of cases, wells can be treated satisfactorily by injecting chemical once every two weeks or once every three weeks, provided that the ratio of chemical used to the amount of gas produced between treatments is somewhat constant. The same criteria are used to determine the effectiveness of chemical treatments as are used to determine the wells with corrosion. That is, the iron content of the produced water, caliper survey and coupon tests along with replacements, if any, indicate the degree of success of the treatments.

Those operating multiple completed condensate wells or condensate wells producing from the casing-tubing annulus are limiting corrosion with organic inhibitors. In most instances the inhibitor is diluted, using 5 to 15 parts of diluent per part of chemical. Some wells, however, are being treated with undiluted chemicals every two to three weeks. These treatments appear to be satisfactory.

Chemicals Favored for High Pressures

Very little data were submitted on wells having pressures above 5000 psi but it was indicated that some of these wells are equipped with 9% Ni tubing, some with N-80 and some with 9% Cr. All those expressing an opinion on how wells having high pressure should be handled indicate that tubing should be selected on a basis of physical properties and that corrosion should be controlled by chemical means. One operator suggested that in extremely high pressure wells it should be feasible to use 2½ inch P-105 tubing with an inside string of 1¼-inch tubing plus continuous chemical injection into the 2½-inch string.

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16 Firms Spend $407,000 to Treat Cooling Water

Procedures for Above Ground Field Tests Of Deicing Salts Are Studied by T-4D

M. B. Hart, Illinois Bell Telephone Company, Chicago, chairman of Technical Unit Committee T-4D on Corrosion by Deicing Salts has appointed members of a task group to study and develop procedures for conducting field tests above ground. Appointed were J. I. Bergman, National Aluminate Company, Chicago; C. T. Roland, Calgon, Incorporated, Pittsburgh; D. A. Spalding, The Dow Chemical Company, Midland, Michigan; S. K. Coburn, Association of American Railroads, Chicago and J. T. Temmerman, City of Rochester, Rochester, New York. To date, no standardized procedures have been developed for conducting field tests above ground. General comment in the committee had revealed that weight loss on test panels attached to the underside, bumpers or other parts of automobiles, trucks would give variable results due to splash of mud, abrasion from flying sand and particles of ice. Comment has also been made that the place and method of attachment of the panel on the vehicle would greatly influence the results and prevent comparisons between cities unless such details are standardized.

Visual Inspection Recommended

One member of the committee feels that visual inspection by an inspection force trained in paint failures, welding failures, molding failures, etc., gives more accurate and conclusive results than test panels. He said such an inspection force is used by one motor car manufacturer and that they inspect for corrosion at the fender welt area, rear gravel deflector, window well and applied molding.

They found corrosion more prevalent in Akron, Ohio and Rochester, New York where inhibitors are used. This was thought to be related to heavy or excessive use of salt, rather than to presence or absence of inhibitors. In general, this inspection force was unable to show that inhibitors caused fewer cars to show corrosion failures. Another member of the committee says it is difficult to evaluate either the corrosion caused by salt, or the benefit of inhibitors when comparing widely separated cities with different atmospheric and industrial environments.

Automobiles Are Protected Now

A member of the committee says that corrosion from the standpoint of car users is becoming somewhat less important since vulnerable spots on automobiles are either being eliminated or better protected. He said plated parts corrode more rapidly in cities using salts than elsewhere.

Another member of the committee comments that sales of inhibited salt are very limited and there is apparently very little demand either because of costs or doubt of benefit. Another member said adding inhibitor to the extent of 1% would mean an increase of about $3 per ton of salt, which otherwise would cost $10.00 to $12.00. He said there is some doubt that even 1% inhibitor would be effective. Another member said that $3.00 might look relatively high but spread over the large number of car users would in the course of the season be much less than a single car washing.

General comment was that there are very few complaints of corrosion on the underside of cars due to the heavy metal of the frame and to coatings of oil, dust and mud. It was agreed that undercoating was doing some good although the increasing number of undercoating materials included some of very doubtful quality. Comment was made that some types of undercoats crack and some even peel or drop off.

Cable Sheaths Are Attacked

Mr. Hart asked the committee for comments on the underground phases of corrosion by deicing salts. Various members reported that lead cable sheath corrosion was increasing as the use of surface trolley lines decreased. One member commented that salt brine definitely increases corrosion in that it decreases resistance to ground current. Mr. Hart said that cable corrosion in one large metropolitan area seems to have decreased slightly. One member credited this to the fact that very little salt has been used in the area for the past two years. Another member reported that corrosion underground was increasing on lead cables, gas pipings and other underground structures in another large metropolitan area.

A supplement to the original bibliography on deicing salts has been submitted to the committee by George E. Best. The supplement has been distributed to the members of the committee. Mr. Best reports that future supplements will be made available to the members as publication references are furnished him.

A nominating committee has been appointed to select nominees for the offices of chairman and vice-chairman of Committee T-4D.

T-4 Officers Active in Utilities Corrosion Field

Dietze

Kulman

F. E. Kulman of Consolidated Edison Company of New York, Inc., has been chairman of NACE Technical Group Committee T-4 on Utilities since the group committee was formed by the reorganization of NACE Technical Com-

(Continued on Page 60)

49 Cooling Towers Dissipate 196 Billion BTU's Every Day

Sixteen companies reported to a working unit of NACE Technical Task Group T-5C-1 on Corrosion by Cooling Waters, South Central Region, that they spent $407,000 yearly for cooling water treating chemicals. The plants operate 49 cooling towers with a combined circulation rate of 1,028,400 gallons a minute and dissipate 196 billion BTU's daily. This report was presented at a May 25 meeting. Maxey Brooke, Phillips Petroleum Co., Sweeny, Texas, is head of the unit.

The report also includes sections on types of treatment used, methods used in making calculations and factors influencing treating costs.

C. P. Dillon reported on the activities of the Non-Ferrous Alloys and Stainless Steels work committee of which he is chairman. A testing program has been initiated to determine the stainless steel alloys most susceptible to stress corrosion cracking in the Gulf Coast cooling waters. Racks for making the tests will be completed and distributed to member companies by the end of 1955. Mr. Dillon also presented a paper entitled "Heat Exchanger Materials versus Plant Cooling Water" authored by W. G. Ashbaugh, Carbide & Carbon Chemicals Co.

J. L. Ragan reported for the Test and Inspection Group in the absence of the chairman, W. G. Ashbaugh. A report of the results of an inter-plant laboratory test conducted by the group was discussed. The group recommended a report be issued for publication giving the committee's recommendations of the best standard laboratory test method for screening corrosion inhibitors for use in cooling waters.

A. S. Krisher of the Monsanto Chemical Company, Texas City, was elected chairman Technical Task Group T-5C-1 on Corrosion by Cooling Waters, South Central Region, at the meeting. Also elected were C. P. Dillon, Carbide & Carbon Chemicals Co., Texas City, vice-chairman, and J. L. Weiss, Diamond Alkali Co., Pasadena, Texas, secretary.

Messrs Krisher, Dillon and Weiss have been active on T-5C-1 since the committee's formation in 1953. Mr. Dillon was the first chairman of the committee and instrumental in organizing it. Mr. Krisher has been chairman of the working groups since the committee formation and was a member of the original group that organized T-5C-1.

The outgoing officers are J. L. Ragan, Celanese Corporation of America, Bishop, Texas, chairman; E. L. Haile, Monsanto Chemical Co., Texas City, vice-chairman and R. H. Maurer, Celanese Corporation of America, Bishop, Texas, secretary. Mr. Haile resigned shortly before the May 25 meeting because of pressing company duties.

Zinn Heads Nuclear Society

W. H. Zinn, director of the Argonne National Laboratory has been elected first president of the American Nuclear Society.

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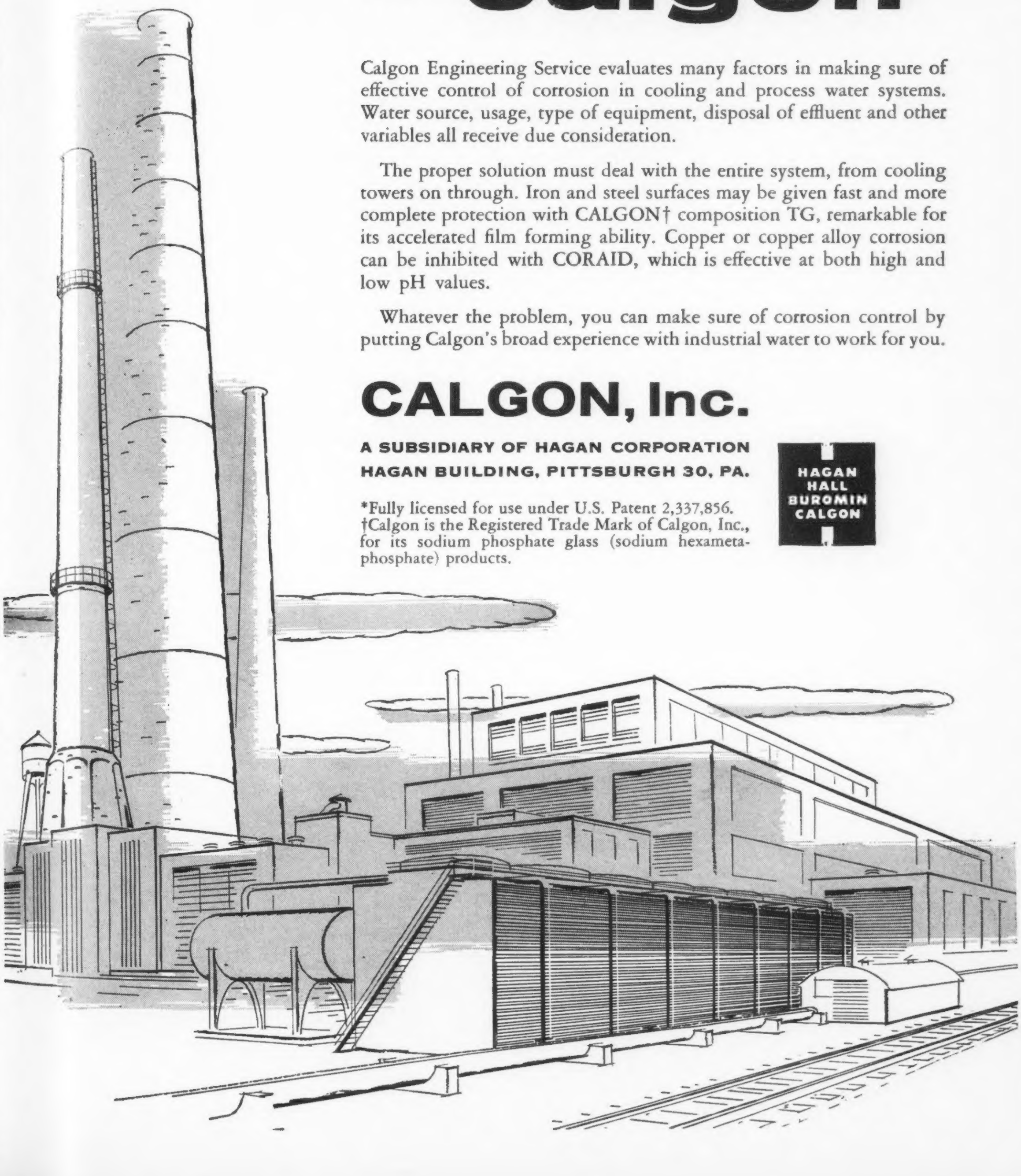

Cooperative Coupon Test Program Considered As Reproducibility Factor Is Found Fovorable

Ivy M. Parker, Plantation Pipe Line Company, Atlanta, Georgia, chairman of T-2E on Internal Corrosion of Products Pipe Lines and Tanks reports that a program begun in March of 1954 to test the reproducibility of coupon testing methods has been completed. She said three coupons were installed by each of three companies at locations ranging from almost perfect conditions to complete rusting conditions. Reproducibility of the results on three coupons in one location was considered excellent with no more than one-half scale rating difference. Dr. Parker has suggested that the results of the reproducibility test were good enough to justify initiating a cooperative coupon test program. The purpose of this program will be to obtain more data on the effectiveness of various inhibitors and permit collection of more information on uninhibited pipe lines. Each cooperating member would expose coupons in his particular line, rate his coupons, photograph them and preserve them. In addition, he would report size of line, flow per hour and inhibitor employed with dosage. Three points to be taken into consideration in the coupon tests were agreed upon by the commitee. These are: 1) coupon positioning and mounting, 2) rating of coupons, and 3) surface preparation of coupons.

Corrosion Attacks Prover Tanks

In a discussion on the effect of corrosion on the volume of prover tanks, (tanks used to calibrate meters) the T-2E committee agreed that corrosion does affect their accuracy. Metallized aluminum linings to prevent corrosion on the inside surfaces of steel tanks gave very good agreement between the final in-and-out meter records. The corrosion products on unlined steel tanks not only reduce volume but also the roughness caused by the corroded surface affects the amount of drain-down. Both factors affect the volume of liquid recovered from a prover tank. Organic coatings were reported as having been used on prover tanks but some objection was raised because it was thought that these coatings have a relatively high swell factor and that this could interfere with tank accuracy. Zinc metallizing was thought to be unsatisfactory because of the possible reaction between gasoline additives, such as tetraethyl lead and the zinc.

Tuberculation In Gasoline Tanks

It has been reported to the committee that tanks containing a gasoline have experienced a relatively mild tuberculation attack on the underside of floating roofs. Pitting of tank bottoms from the liquid side was said to be a problem by several members of the committee. This was conceded generally to be caused by the bottom sedimentation which often is present as an undrainable layer. Use of magnesium anodes to prevent this type of bottom pitting was reported. They are placed on a tank bottom and on top of current dispersing pads. One installation in crude oil was expected to have a life of three to four years with resistors installed in series with the anode to limit current output. It was estimated that without these resistors, life of the magnesium anode installations would be one year only.

Inhibitors Protect Shell Only

Many T-2E committee members say oil-soluble corrosion inhibitors are effective in preventing corrosion only on the shell portions of storage tanks. These inhibitors have no effect on the undersides of cone-roofed storage tanks, nor do they appear to inhibit pitting on the liquid side of the bottoms. Failure of oil-soluble corrosion inhibitors to prevent bottom pitting was thought to be attributable to the layer of bottom sludge and waste. A number of the member reports indicated that tanks which had been storing inhibited products for a period of three to four years had nevertheless developed bottom pits in spite of the inhibitor in the commodity.

Improved Combustion Goal

Improved combustion should be the first major goal of industry in reducing smog, according to Lauren B. Hitchcock, president of the Air Pollution Foundation in an article published in July "Scientific Monthly."

T-4 Officers Active—

(Continued From Page 58)

mittees in March, 1954. Mr. Kulman was born in Brooklyn, New York, in 1905, obtained his BS degree in 1926 from the College of the City of New York. After employment in the operating department of the Brooklyn Edison Company, he joined the New York Edison Company as tester in the test department, assisting the electrolysis engineer in periodic and special corrosion investigations on the underground cable and gas piping systems in the City of New York. From 1926 to 1935 he attended the evening session of the Polytechnic Institute of Brooklyn where he received the degree of Electrical Engineer in 1931 and Master of Electrical Engineering in 1935. In 1936 Mr. Kulman became a licensed professional engineer in New York State. During 1938 and 1939, as junior engineer for Consolidated Edison Company of New York, he was in responsible charge of laboratory tests on high voltage cable joint designs, net work protectors and relays, cable limiters and other equipment.

In 1940, Mr. Kulman was transferred to engineering work in the outside plant bureau where he assisted in the planning and design of corrosion mitigation measures for the electric transmission and distribution system and the gas piping system. During World War II he was an officer in the Naval Reserve and was assigned to a large bureau of Ships Materiel Laboratory where he was in charge of personnel administration of scientists and engineers.

In 1946 Mr. Kulman returned to his civilian position in corrosion engineering and since 1951 he has been engineer in responsible charge of corrosion design of the Consolidated Edison Company's underground plant, including pipe type lead sheath cable and the gas steam piping systems. His responsibilities include the mitigation of stray current electrolysis, specification of materials for corrosion protection, development and design of cathodic protection systems and general planning of the annual survey program of the underground plant. Mr. Kulman became a member of NACE in 1946 and also is a member of the American Institute of Electrical Engineers, American Gas Association and the National Society of Professional Engineers.

He is active in the Naval Research Reserve and holds the rank of Commander USNR. He has been the author or coauthor of technical papers presented before the AIEE, AGA and NACE. He has been a special member of the AIEE Insulated Conductor Committee, a member of the AGA Corrosion Committee, Chairman Sub-Committee on the Causes of Corrosion. In NACE his committee work has included membership in T-4B, Corrosion of Cable Sheaths; chairman T-4B-3, Tests and Surveys; T-4D, Corrosion by De-Icing Salts. Mr. Kulman currently is vice chairman of the NACE Metropolitan New York Section, chairman of the Greater New York Committee on Corrosion, co-chairman of local arrangements for the forthcoming NACE Twelfth Annual Conference and Exhibition to be held in New York City in March, 1956.

Irwin C. Dietze of the Department of Water and Power, Los Angeles, California, was elected by letter ballot vote by members of Technical Group T-4 to serve as vice-chairman of T-4. Mr. Dietze is a native born Californian. He joined the Los Angeles Department of Water and Power in the Underground Section of the Design and Construction Division after graduating from the University of California and has just completed his 30th year with the department. During the last 25 years he has been actively engaged in electrolysis and corrosion work.

He is a member of the American Institute of Electrical Engineers and of the AIEE Cathodic Protection Sub-Committee of the Committees on Chemical, Electromechanical and Electrothermal applications.

He is chairman of the Electrolysis Committee of Southern California. He has been a member of the National Association of Corrosion Engineers since 1945, in which he has held or now holds the following offices: Program chairman of the Western Regional Division in 1947, chairman of Western Regional Division in 1948, NACE director representing the Western Regional Division for three years, 1949 through 1951; correspondent for CORROSION Magazine representing the power industry from 1948-1949; chairman of NACE Technical practices Committee TP 16, Electrolysis and Corrosion of Cable Sheaths which was organized in 1950. (This committee is now known as Technical Unit Committee T-4B); vice-chairman for NACE Technical Committee T-4 on Utilities, member of NACE Editorial Review Sub-Committee of Corrosion since 1953. Mr. Dietze presented a paper before the NACE Conference in 1947 entitled "Cathodic Protection of 138 KV Lead Sheathed Power Cables in the Los Angeles Department of Water and Power" which was published in Corrosion September, 1947.

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The Bibliographic Survey of Corrosion for the years 1950-51 includes 4454 abstracts of literature topically indexed and cross-indexed.

Several New Solutions to Tank Car Corrosion Problems Suggested at May 9 T-3E Meeting

At a meeting of Unit Committee T-3E on Railroads in Washington, D. C. May 9, a member of the committee commented on the use of aluminum tank cars for transporting ammonium nitrate. He suggested that an alternative system, using aluminum metallizing with an epon resin sealer would meet the requirements for ammonium nitrate service. Mention was made of the experimental use of magnesium anodes in benzol tank cars for preventing corrosion of heating coils in the bottom of the car which was not too successful. Another method to combat corrosion in tank car coils would be to preferentially wet the inside of the tank car before loading with benzol. Another member of the committee said that painting the coils is impossible because of the confined space and inaccessible areas involved. Santolene C or similar rust inhibitor in a concentration of 20 ppm was mentioned as a possible inhibitor for introduction into benzol.

In a general discussion at the meeting, one comment concerned a cold spray paint for exterior of freight cars. He said it had low solvent-high solids concentrations, thus giving dry-film thicknesses of up to 1.75 mils per coat. Present advertisements state 2.5 mils may be obtained. Conventional spray equipment may be used in application, as the paint exhibits excellent viscosity characteristics. The cost involved is somewhat higher than those of conventional painting methods.

An inquiry was made of the committee concerning the corrosion of covered hopper cars by rock salt. The thought was expressed that vinyls or epons would be suitable for this service although vinyls often build up static charges. Surface preparation for this system should consist of sand or grit blasting, taking care that proper particle size is employed. The height of the asperities in the metal before coating should not be greater than one-third the final dry film thickness.

The use of inhibited 1,1, 1 trichloroethane as a cleaner for electrical equipment was discussed. It possesses low toxicity in comparison with carbon tetrachloride, good cleaning characteristics and is not flammable.

ERRATUM

Summary of Data on Use of Structural Plastics in Oil Production. Corrosion, Vol. 11, No. 6, Page 59 (Technical Committee Activities) (1955) June.

Substitute the arrangement of figures below for those in upper left hand corner of Page 62. In effect transposing cutlines under figures.

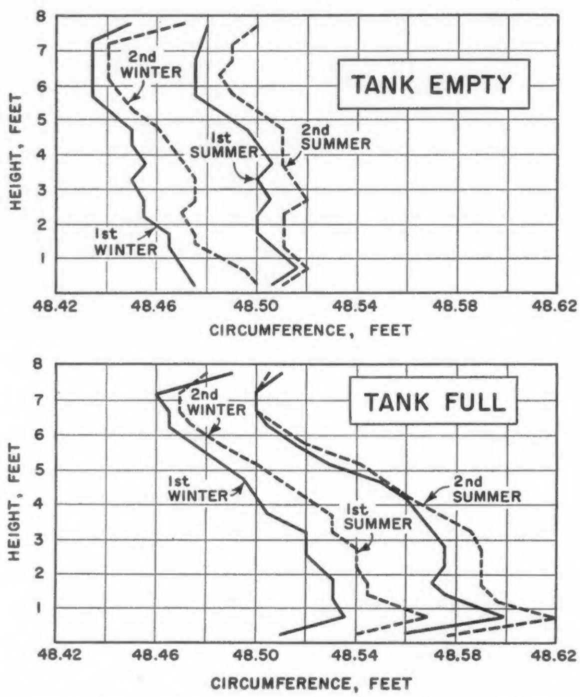

Figure 4—Circumferential measurements of glass-polyester stock tank.

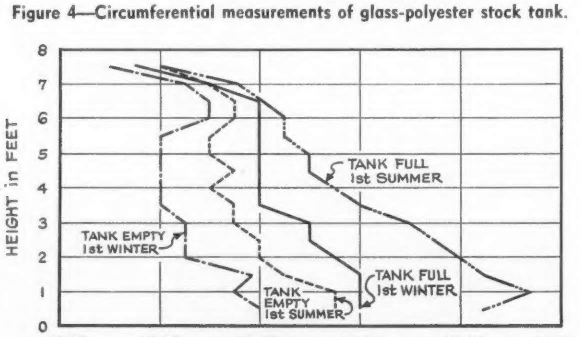

Figure 5—Circumferential measurements of glass-epoxy tank.

Results Reported On Over 2000 High Silicon Anodes

It has been reported to Unit Committee T-2B on Anodes for Impressed Current that during the year March 1953-March 1954 over 2000 high silicon cast iron anodes were placed in field applications of various types. While results of these field tests cannot be obtained in such a comparatively short time, an attempt was made to outline general trends that have been established.

In addition, certain basic laboratory data had been obtained that fits into the general picture. A manufacturer of the high silicon anodes submitted to Committee T-2B a report which was subdivided into three general categories: Ground bed, salt water and fresh water. The report says a large number of the high silicon cast iron anodes have been installed in a wide variety of ground applications but very little information is available to date.

Several installations were made in cooperation with members of Committee T-2B. These initial trials include installations in swampy areas where low resistivity conditions exist, in soils having high acidity from adjacent coal piles or acid distributing systems, in soils in coastal areas where sea water is present and in special sulfate soils known to be troublesome.

Backfill Often Omitted

In many cases the installation of the high silicon cast iron anode was made because graphite showed an unsatisfactory life. They were applied without benefit of backfill where backfill was not practicable and in other instances backfill was intentionally omitted to produce a broader evaluation. In still other instances, comparisons are being made with graphite under similar installation conditions. Trial installations involve not only pipe line applications but include such other underground structures such as tanks, telephone cables, etc.

The report to T-2B indicates that a gas blocking situation possibly may be a problem in chloride-saturated soils. The problem is presently being investigated

(Continued on Page 64)

Results Reported–

(Continued From Page 62)

by studying more suitable backfill methods and other anode materials. In addition to backfill studies for the chlorine problem, other possible backfill materials are being investigated for economic reasons.

Salt water tests indicate a very general suitability of the high silicon cast iron anodes and in numerous trial installations to date no substantial deviation from laboratory data has been reported. In general, it has been found that the electrical characteristics of the high silicon cast iron anode and graphite anode are equivalent. Laboratory tests in synthetic sea water verify this conclusion.

Surface Resistance Constant

The low specific resistance and back EMF values of the high silicon anodes appear to be counterbalanced by a somewhat higher surface resistance. This surface resistance does not seem to change with time. Again in both laboratory and field installations some limited evidence of gas blocking was noticed. In the laboratory this condition was overcome by eliminating taped joints and the only evidence of chlorine corrosion in the field occurred on anodes which also had taped joints. If a gas blocking problem does exist, it may be eliminated by selection of another anode material or change of installation design.

From the numerous high silicon cast iron anodes in field tests, there is every indication that high silicon anodes has a very low consumption rate under all conditions in fresh water. In one field test, a single anode replaced one of several aluminum anodes in a relatively small water storage tank. As the parallel aluminum anodes continued to build up resistance from corrosion products, the high silicon cast iron anode passed increasing current since no surface build-up resulted. The high silicon cast iron anode surface remained bright and shiny and had no bad effect on the water. Based on these results, high silicon cast iron replaced aluminum in this installation and was reported to have essentially the same electrical characteristics as a newly installed aluminum system. Laboratory data indicate this to be true at the high current densities.

Initial laboratory and field tests indicate oxygen has no damaging effect on high silicon cast iron anodes. Although chlorine has had a damaging effect under tape and at other restricted areas, this effect was not noticeable with oxygen.

Tests Made in River

One company represented on T-2B installed two 2-inch x 60-inch high silicon cast iron anodes in the Hudson River at Yonkers, New York. The anodes were of experimental design and no attempt was made by the manufacturer to provide a wire connection other than a piece of galvanized iron cast into one end of the anode. The wire connection provided by the company consisted of a 25-foot length of wire over which had been slipped an 8-inch length of automobile radiator hose. A current of 20 amperes was impressed on each anode and resulted in an anode-to-river potential of 15 volts. This created an effective resistance of approximately 0.75 ohm.

Approximately one month later or after 15,840 ampere hours the anodes were removed for inspection. The average weight loss was 3.8 pounds which computed to 2.1 lb. per ampere year. The observed corrosion was fairly uniform except for a slight tendency to neck adjacent to the rubber hose.

Another member company installed in the harbor of New Rochelle, New York four 2-inch x 60-inch cast iron anodes in an installation similar to the one recorded above. A current of 44 amperes was impressed on the group. After service of 17,500 ampere hours the anodes were removed for inspection. Each of the four anodes had corroded fairly heavily on one side. It was believed, although not definitely known, that the heaviest corrosion was on the bottom and caused by chlorine trapped in the mud. There was also a marked necking tendency adjacent to the rubber hose. Total weight loss was only 4 pounds per anode or 2 pounds per ampere year.

Since both tests showed a necking effect at the rubber hose connection new anodes were used in the second test. An average current of 11 amperes was used for a total of 29,000 ampere hours. The average weight loss was 4.5 pounds or 1.36 pounds per ampere year. An anode in the group provided with protecting rubber hose showed a bad necking effect with an average diameter of 1.65-inch just below the hose while the average diameter at the center of the anode was 1.94-inch. An anode which had been cut back to provide a uniform diameter between the exposed anode and the hose

(Continued on Page 66)

Results Reported—

(Continued From Page 64)

for an unknown reason showed the greatest tendency to neck, adjacent to the end of the hose at a joint which had been 2 inches in diameter. The average diameter was only 1.49-inch. Two anodes used without the rubber hose reinforcement of the connection seal showed a slight tendency to taper off at each end but the deep necking was completely absent. These tests indicate that the attempt to reinforce the anode connection with automobile radiator hose in all cases has led to severe necking. The manufacturers' connection without reinforcement showed no deterioration after 4 months' service at 11 amperes per anode.

Installed in Quicksand

Another company installed high silicon cast iron anodes in quicksand with no special backfill. The soil resistivity in both ends of the ground bed site at this experimental anode installation was in the order of 2400 ohm-centimeter near the surface but appreciably higher at lower depths. Analysis of the soil readings led to restricting the anode depth to 9 feet. The anode bed was designed to have an anode bed life of approximately 20 years. The company plans to take data twice a year through 1957 in order to get continuing information on the installation.

A report has been furnished the committee on an installation of high silicon cast iron anodes under observation in an office building storage tank containing New York City water. The storage tank in question was protected with aluminum anodes with impressed current from a rectifier. The first high silicon cast iron anode installation consisted of a 2-inch by 5-foot high silicon cast iron anode which was used to replace an aluminum anode showing the most rapid attack. The replacement anode had been in service for 458 days, during which time it had discharged approximately 6400 ampere hours with a weight loss of 2 ounces from an original weight of 48 pounds. This is equivalent to approximately 0.17 pounds per ampere year. At this rate it would take nearly 100 years to consume 25% of the original anode weight at the present current output of approximately .7 of an ampere for the anode.

Screwed Joints Protected

At a later date, after the aluminum anodes continued to deteriorate and it became necessary to make replacements, it was decided to install sample high silicon cast iron anodes in the 1-inch by 60-inch size with Monel inserts at each end to permit joining adjacent lengths with threaded stud. Each replacement anode in the water tank would have one joint under water because there would be 15 anodes installed, so it was decided to check various means of insulating the screwed joints.

Four different types of joint protection was used as follows: 1. Joint assembled with Neoprene washer as furnished by manufacturer between butting anode ends at the joint with the joint protected by polyvinyl chloride insulating tape. 2. Joint assembled with Neoprene washer as above and protected with polyethylene tape. 3. Joint assembled with Neoprene washer between anode ends as above but without any further protection. 4. Joint assembled with all threaded portions and anode ends coated with heavy grease without using Neoprene washer or any other means of protection. In all cases where a Neoprene washer was used as a seal between butting anode ends there was no penetration of moisture past the washer to the Monel inserts or connecting stud bolts.

Slight Attack Reported

Another member of the committee reported on his experience with high silicon cast iron anodes in fresh water application, salt water applications and soil installations. His general observation on performance of high silicon cast iron anodes in fresh water 4000 to 8000 ohm-centimeter resistivity indicates that attack is very slight over a period of six or seven months during which time approximately 3000 ampere hours of electrical energy per anode was discharged.

Cross sections of the anodes were taken and found to indicate very little reduction. In a salt water application where the water resistivity ranges from 30 to 50 ohm centimeters with some sewage content two 2-inch x 60-inch graphite anodes were replaced by two 2-inch x 48-inch high silicon cast iron anodes. The original current output per anode was 4 amperes each. After the anodes had discharged between 10,000 and 15,000 ampere hours they were pulled for inspection. The original casting marks were still visible and the only obvious effect of the current discharge was a thin film on the anode surface.

NACE News

Programs Are Given for Three Regional Meetings

19 Committees Will Convene at Houston; 10 Symposia Set

Ten symposia, one with two sessions have been scheduled for the NACE South Central Region meeting to be held in Houston October 18-21. All sessions will be at the Shamrock Hotel. H. E. Morris, Monsanto Chemical Co., Texas City, is technical program chairman.

Nineteen technical committees already have scheduled meetings during the session and others may be held.

The following schedule of symposia has been arranged tentatively:

Thursday, October 20: Morning—Pipe Line, High Temperature, Recirculated Water I; afternoon—Recirculated Water II, Oil and Gas, Protective Coatings.

Friday, October 21: Morning—Inhibitor, Utilities, Marine; afternoon—Cathodic Protection, Chemical Industry.

Announcements have been made of the papers to be presented during some of the symposia. Among these are the following:

Corrosion and Inhibitor Symposium

Chairman Norman Hackerman, University of Texas, Austin.

A Laboratory Method for the Evaluation of Oil Production Corrosion Inhibitors by David B. Boies, National Aluminate Corp., Chicago.

Corrosion Investigations Related to Adsorption Studies by C. C. Nathan, The Texas Co., Bellaire, Texas.

Sulfonates as Corrosion Inhibitors by A. H. Roebuck, P. L. Gant, O. L. Riggs and J. D. Sudbury, Continental Oil Co., Ponca City, Okla.

Control of Couples Developed in Water Systems by G. B. Hatch, Calgon, Inc., Pittsburgh, Pa.

Inhibiting Corrosion of Steel, Aluminum and Magnesium Intermittently Exposed to Brines by George E. Best and J. W. McGrew, Mutual Chemical Division, Allied Chemical and Dye Corp., Baltimore, Md.

Cathodic Protection Symposium

Chairman Gordon Doremus, Cathodic Protection Service, Houston.

A High Potential Magnesium Anode, P. F. George, J. J. Newport and J. L. Nichols, The Dow Chemical Co., Midland, Mich., and Freeport, Texas.

Cathodic Protection Rectifiers: Some Factors to be Considered in Specifications and Design, Lyle R. Smith and Earl Newmyer, Good-All Electric Mfg., Co., Ogalalla, Neb.

Application of Cathodic Protection to Internal Tank Bottoms, J. W. Graves and O. R. Tisdale, Tidal Pipe Line Co., Houston.

(Continued on Page 68)

Western Region's Agenda Includes Four Symposia

Four symposia and two special reports are among the events scheduled during the Fifth Annual Western Region Corrosion Conference to be held at San Francisco November 17 and 18. The conference will follow the 3-day short course at University of California, Berkeley, November 14-16 inclusive. The NACE conference will be held at the Sir Francis Drake Hotel, San Francisco. D. Roger Loper, Standard Oil Company of California is technical program chairman.

The tentative program is as follows:

Thursday, November 17

Symposium on Pipe Line Protection Problems: Holiday detection equipment, use of inhibitors, internal coating of natural gas pipelines, external coatings and plastic pipe lines.

Symposium on Ocean-Going Vessels: Protection of tanks on tanker ships, protection against hull corrosion, electrolytic descaling.

Special Reports: Cracking problems in stainless alloys. Report on research in use of wood in cooling towers.

Friday, November 18

Symposium on Corrosion Problems With Oilwell Casing and Tubing: General problems and types of corrosion, use of inhibitors, cathodic protection against external corrosion.

Symposium on Corrosion Problems in Offshore Drilling.

Committeemen Responsible For Session Are Named

Members of the committee responsible for arrangements at the Northeast Region's October 31-November 3 meeting at Niagara Falls are:

J. M. Fouts, New York Telephone Co., program chairman; E. F. Dunn, Whitehead Metal Products Co., Inc., arrangements chairman; D. W. Hengerer, Kem-E-Quip Corp.; R. H. Shaffner, Prufcoat Laboratories, Inc., Fellowship Hour; E. K. Benson, New York Telephone Co.;

A. Fini, Niagara Mohawk Power Corp.; R. C. Larabee, American Telephone and Telegraph Co.; R. L. Seifert, Tennessee Gas Transmission Co.; H. W. Staderman, Niagara Mohawk Power Corp.; E. L. Varney, Iroquois Gas Corp.

Davis Is On Committee

R. A. Davis, Chicago Bridge & Iron Company, Birmingham, Alabama, has accepted an appointment to serve on the Policy and Planning Committee of which E. P. Noppel is chairman.

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Corrosion is available on a subscription basis to non-members of NACE.

15 Technical Papers, Other Events Listed For Niagara Falls

Fifteen technical papers, a general discussion session and numerous other technical and social events have been scheduled during the Northeast Region's Oct. 31-November 3, 1955, meeting at Niagara Falls, N. Y. Also scheduled are meetings of several NACE technical committees.

J. M. Fouts, New York Telephone Co., Buffalo, program chairman said the meeting titled "Conference on Underground Structure Corrosion," will include a number of social events, panels and a banquet November 2 to be addressed by Rob Roy Macleod, Niagara Mohawk Power Corp., Buffalo. Special events arranged for ladies accompanying registrants include a luncheon and a tour of the scenic areas around the United States and Canadian falls on November 2.

A tentative program, including approximate titles of papers to be presented has been released as follows:

Title: Conference on Underground Structure Corrosion including steam generating station and pipe line compressor station corrosion problems.

Sponsors: Northeast Region NACE and Niagara Frontier Section.

Headquarters: Hotel Niagara, Niagara Falls, N. Y.

Tentative Program

Monday, Oct. 31

9 am-5 pm—Technical Committee meetings.

12 noon-8 pm—Registration.

Tuesday, November 1

8 am—Registration opens.

9-9:45 am—Fundamentals of Corrosion, Thomas P. May, The International Nickel Co., Inc., New York.

9:45-10:30 am—Fundamentals of Corrosion Testing on Underground Plant, Vernon B. Pike, Bell Telephone Laboratories, Murray Hill, N. J.

10:30 am-10:45 am—Intermission.

10:45-12 noon—Panel and general discussion.

12 Noon—Luncheon.

1:30-2:15 pm—Testing Methods and Corrosion Control Measures for Buried Telephone Cables, Daniel R. Werner, American Telephone and Telegraph Co., Long Lines Dept., Kansas City.

2:15-3 pm—Corrosion Control Practices for Pipe-Type Cables on the Detroit Edison System, W. A. Sinclair, Detroit Edison Co., Detroit.

3-3:15 pm—Intermission.

3:15-4:40 pm—Panel and general discussion.

7:30 pm—Niagara Frontier Section Annual Business Meeting and Election of Officers.

(Continued on Page 68)

Management's Attitude Discussed at San Diego

At the June 15th meeting of the San Diego Section, 35 members and guests heard Paul Beerman and Linn E. Magoffin speak on the subjects of "Management's Attitude on Corrosion" and "Construction of a Deep Vertical Anode," respectively. Mr. Beerman discussed the qualifications, work and results expected by management of a corrosion engineer. Mr. Magoffin showed colored slides and discussed vertical anodes placed 350 feet deep in the earth by the California Water & Telegraph Company.

Much interest was shown in the discussion and the question period which followed lasted approximately half an hour.

Carolinas Section Has Dinner Business Session

A dinner and a business session concluded the one-day meeting June 17 of the Carolinas Section held in conjunction with the annual Sea Horse Institute of the International Nickel Company.

The morning session was a joint meeting devoted to illustrated discussions of cathodic protection and coatings.

The afternoon portion of the meeting was a tour of the International Nickel Company's Harbor Island Testing Station. During the tour, R. B. Teel, vice-chairman of the Carolinas Section, described the multitude of tests being conducted by International Nickel, giving the technical background of the tests and answering questions concerning operations at the station.

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Abstracts published in the NACE Bibliographic Surveys of Corrosion are obtained from more than 28 abstracting agencies.

19 Committees—

(Continued From Page 67)

Marine Corrosion Symposium

Co-Chairmen P. F. Dial, Jr., The Pure Oil Co., Houston and O. L. Grosz, The California Co., Harvey, La.

Cathodic Protection of Offshore Platforms, W. H. Edwards, Superior Oil Co., Houston.

Structural Design for Offshore Corrosion Control, D. B. Stauffer, Humble Oil and Refining Co., Houston.

Economic Considerations of Corrosion Control of Offshore Drilling and Producing Equipment, F. E. Blount, Magnolia Petroleum Co., Dallas.

Plastic Coated Magnesium Anodes, B. Douglas and C. F. Schrieber, The Dow Chemical Co., Midland, Mich.

Oil and Gas Industry Symposium

Chairman W. F. Oxford, Jr., Sun Oil Co., Beaumont.

Iron-in-Oil Technique as a Corrosion Control Criterion, R. G. Rydell National Aluminate Co., Chicago and Al Walker and Reed Robertson.

Report of Some Metallurgical Investigations for Materials to Control Corrosive High Pressure Wells, B. B. Morton, The International Nickel Co., Inc., New York.

Cathodic Protection of Oil Well Casings, G. L. Doremus, Cathodic Protection Service, Houston.

A Report on the Use of Alco Plating (Electroless Nickel Plating), author not named, Alco Products, Beaumont, Texas.

Round Table Discussion

Moderator Derk Holsteyn, Shell Oil Co., Houston. Panel members: Lionel Morrow, Interstate Oil Pipe Line Co., Shreveport, La.; L. P. Sudrabin, Electro Rust-Proofing Corp., Newark, N. J.; Scott Ewing, Carter Oil Co., Tulsa; Starr Thayer, consultant, Houston.

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More than 1400 copies of Corrosion are mailed monthly to addresses outside the United States.

15 Technical—

(Continued From Page 67)

Wednesday, November 2

8 am—Registration.

9-9:30 am—Protection of Gas Service Distribution Lines from Corrosion, Charles W. Beggs, Public Service Electric & Gas Co., Newark, N. J.

9:30-10 am—Wax Type Coatings, Ted Kennedy, Jr., The Trenton Corp., Ann Arbor, Mich.

10-10:30 am—Coal Tar Pipe Coatings, Norman T. Shideler, Pittsburgh Coke & Chemical Co., Pittsburgh.

10:30-10:45 am—Intermission.

10:45-12 noon—Panel and general discussion.

12 noon—Luncheon.

Panel on Corrosion Problems in Steam Generating Stations and Pipe Line Compressor Stations

1-1:30 pm—Problems of Corrosion in Large Steam Generating Stations, Thomas J. Finnegan, Niagara Mohawk Power Corp., Buffalo.

1:30-2 pm—Application of Brass and Cupro-Nickel Alloys in Corrosion Problems in Steam Generating Stations and Pipe Line Compressor Stations, A. W. Tracy, American Brass Co., Waterbury, Conn.

2-2:30 pm—Application of High Nickel Alloys in Corrosion Problems in Steam Generating Stations and Pipe Line Compressor Stations, J. F. Mason, Jr., International Nickel Co., Inc., New York.

2:30-3 pm—Application of Metallizing in Corrosion Problems in Steam Generating Stations and Pipe Line Compressor Stations, Herbert S. Ingham, Metallizing Engineering Co., Westbury, L. I.

3-3:15 pm—Intermission.

3:15-4:30 pm—Panel and General discussion.

6-7 pm—Fellowship Hour in the Terrace Room.

7-8:15 pm—Banquet in Main Ballroom.

8:15 pm—Speaker of the evening, Rob Roy Macleod, Commercial Vice-President, Western Division, Niagara Mohawk Power Corp., Buffalo, N. Y.

Thursday, November 3

8 am—Registration opens.

9-9:30 am—Drainage Current Distribution in Cathodic Protection Systems, Marshall E. Parker, Houston.

9:30-10 am—Cathodic Protection of Lead Cables in an Urban Area, Lester M. Plym, Illinois Bell Telephone Co., Chicago.

10-10:30 am—Locating Cathodic Protection Interference Currents and Arriving at Mutually Satisfactory Solutions Through Cooperative Arrangements, Carl E. Erickson, Jr., The Peoples Natural Gas Co., Pittsburgh.

10:30-10:45 am—Intermission.

10:45-12 noon—Panel and general discussion.

12 noon—Luncheon.

1:30-3 pm—Organization and Experiences of the Louisville, Ky., Joint Electrolysis Committee, S. H. Gates, Southern Bell Telephone & Telegraph Co., Louisville and L. P. Aker, Louisville Gas and Electric Co.

3-4:30 pm—Panel and general discussion. Of especial interest to those concerned with joint cathodic protection problems. The Louisville committee of which both speakers are members is considered one of the most successful in the nation.

Chairmen for Houston Short Course Appointed

Chairmen for the next Houston Section Short Course have been announced by Alvan Richey, Cathodic Protection Service, section chairman. They are: C. L. Woody, United Gas Corporation and J. H. Spracklin, Transcontinental Gas Pipe Line Corp. Dates for the short course have not been announced.

Committeemen Named for Houston Section Activities

Members of the various committees who will work with Houston Section officers in section activities during the coming year have been announced by Alvan Richey, Cathodic Protection Service, section chairman.

On the program committee are J. A. Rowe, Jr., Gulf Oil Corp.; M. E. Holmberg; M. C. Forbes, Aquatrol, Inc.; Gordon Doremus, Cathodic Protection Service and L. G. Sharpe, Napko Paint & Varnish Works.

On the arrangements committee are H. C. Morgan, Gulf Oil Corp., chairman; with Harold K. Haynes; Donald E. Montague; and Eugene Eutsler, F. H. Maloney Co. as members. Chairman of the corporate and active membership committee is Sidney Smith, Napko Paint & Varnish Works. In charge of publicity is Ira Mayhew, F. J. Maloney Co., chairman; with Melvin Judah, Pipe Line Industry magazine as committe member. The committee on entertainment and funds is composed of C. B. Tinsley, Southwestern Bell Telephone Co., chairman and Jean S. Wood, Haynes-Stellite Co. and Ken Snyder, members.

On the committee in charge of the 1955 South Central Region meeting to be held in Houston Oct. 18-21 are: Mr. Richey, chairman; Joe Caldwell, Humble Oil & Refining Co., assistant to the chairman; H. E. Morris, Monsanto Chemical Co., technical program and O. W. Wade, Transcontinental Gas Pipe Line Corp., arrangements.

M. C. Forbes, Aquatrol, Inc., and Maurice Riordan, Rio Engineering Co. will represent the Houston Section on the Houston Engineers' Council, with J. H. Spracklen, Transcontinental Gas Pipe Line Corp. and F. W. Gartner, Jr., F. W. Gartner Co. as alternates.

Rutherford Is Elected by Alloy Casting Institute

Thomas Rutherford, The Midvale Co., Philadelphia was elected president of the Alloy Casting Institute June 28 at the close of the institute's annual meeting at Hot Springs, Va. Bradley B. Evans, Empire Steel Castings, Inc., Reading, Pa. was elected vice-president and E. A. Schoefer, Mineola, N. Y. was reelected executive vice-president and treasurer.

ELDON H. MOOT

Eldon H. Moot, Western District Manager, Valdura Div., American-Marietta Co., 140 Shear St., San Francisco, Cal., was killed in an automobile accident May 23 enroute to a business call at Moffett Field.

Water Flood Corrosion Topic at Houston August 9

Corrosion in Water Flood Operation will be discussed at the August 9 meeting of the Houston Section, National Association of Corrosion Engineers. H. L. Bilhartz, Production Profits, Inc., Dallas, will be the speaker. The meeting will be at the Ben Milam Hotel and will start with a fellowship hour at 6:00 pm with dinner at 7:00 pm and the technical meeting at 8:00 pm.

Mr. Bilhartz will define the part corrosion and its secondary problems play in water flooding. He will discuss the causes of corrosion and will describe the engineering methods of diagnosing corrosion mechanisms. The anticipation of problems at the conception of the project will be discussed and the use of pilot floods to assess the importance of the corrosion problems will be described. The preventive and remedial measures commonly employed will be given and the methods of evaluating preventive measures will be considered. Corrosion specimens taken from water flooding projects representing many types of corrosion will be on display.

Section meetings, held at Kelley's Dining room for the past several months no longer will be held there, according to Alvan Richey, Cathodic Protection Service, Section Chairman. A committee will select a new meeting place.

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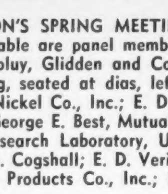
The Bibliographic Survey of Corrosion for the years 1950-51 includes 4454 abstracts of literature topically indexed and cross-indexed.

AT NORTHEAST REGION'S SPRING MEETING. Top—Discussion after Underwater Corrosion Symposium. Behind the table are panel members, left to right: Carl R. Johnson, Port Authority of New York; R. P. Devoluy, Glidden and Co.; W. W. Cranmer, Philadelphia Naval Shipyard; bottom, luncheon meeting, seated at dias, left to right: E. C. Reichard, Holmdel, N. J.; E. A. Tice, The International Nickel Co., Inc.; E. D. Brink, M. B. Jacobs, F. E. Kulman, Consolidated Edison Co.; A. C. Ford, George E. Best, Mutual Chemical Division, Allied Chemical & Dye Corp.; R. B. Mears, Applied Research Laboratory, United States Steel Corp.; F. J. LeFebvre, Electro Rust-Proofing Corp.; J. M. Cogshall; E. D. Verink, Aluminum Company of America; G. F. Gilbert, Jr., Atlas Mineral Products Co., Inc.; S. W. Shepard, Chemical Construction Co.

Rench Will Talk at Permian Basin Meet

Joseph E. Rench, Napko Paint and Varnish Co., Houston, will speak on "What Paint Ain't" during the Permian Basin Sixth Biennial Corrosion Tour. He will speak at 8 p. m. October 13 at the Lincoln Hotel Odessa. The tour will be held October 12-14 in the area centered around Midland and Odessa. It is sponsored by Permian Basin Section, National Association of Corrosion Engineers.



Rench

Mr. Rench's talk will pertain to coatings and their application from a negative point of view. Facts the manufacturer sometimes fail to reveal about his product and which should be known by the user will be discussed.

The tour will consist of visits in air conditioned buses to sites where some 300 pieces of equipment will be available for inspection. Results of mitigation measures extending for periods of more than six years will be observed. Nightly discussions will be held on the facts developed by the inspections.

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Corrosion magazine's abstract section includes over 1400 abstracts a year.

NATIONAL, REGIONAL MEETINGS and SHORT COURSES

1955

Oct.

12-14—Sixth Biennial Permian Basin Corrosion Tour.

Oct. 18-21—South Central Region, Shamrock Hotel, Houston

Oct. 31-Nov. 3—Northeast Region meeting, Hotel Niagara, Niagara Falls, N. Y.

Nov. 17-18—Western Region, Sir Francis Drake Hotel, San Francisco, California

1956

Mar. 12-16—NACE 12th Annual Conference and Exhibition, Statler Hotel, New York City.

Oct. 2-5—South Central Region, Beaumont, Texas

1957

Mar. 11-15—NACE Annual Conference, Kiel Auditorium, St. Louis, Missouri

1958

Mar. 17-21—NACE Annual Conference, Civic Auditorium, San Francisco, California

1959

NACE Annual Conference, Sherman Hotel, Chicago, Illinois.

SHORT COURSES

1955

Sept. 12-16—Washington University, St. Louis.

November—University of California—NACE Western Region. Process Industries.

Dec. 5-9—University of Illinois, Urbana.

1956

Feb. 15-17—Tulsa Section Seventh Annual Corrosion Short Course for Pipeliners, Mayo Hotel, Tulsa, Okla.

Lubrication Conference

The Second Joint Lubrication Conference of the Lubrication Activity Committee of the American Society of Mechanical Engineers and the American Society of Lubrication Engineers is scheduled to be held at the Antlers Hotel, Indianapolis, Ind., October 10-12. Twenty-eight papers in six sessions are scheduled.

Fill Out and Mail to: E. O. Kemper, Permian Enterprises, Inc., Odessa, Texas

Enclosed find $20 as Registration Fee for the SIXTH BIENNIAL PERMIAN BASIN CORROSION TOUR for: (Please print or typewrite)

Name

Company

Address — Street, City and State

If you want the Registration Committee to reserve hotel accommodations indicate for which dates:

October 12 ( ) 13 ( ) 14 ( )

Registration fee includes: Air-conditioned busses, barbecue, lunches, tour report booklet.

Role and Function of Corrosion Engineer In Modern Industry Described by Noppel*

Corrosion is as old as time but not as fleeting. The nation's bill for corrosion is variously estimated in the range of 5 billion to 6 billion dollars a year.

As a result, American industry is becoming increasingly aware of the importance of the corrosion engineer in our economy. It was not too many years ago when corrosion was generally considered to be a necessary evil—something that had to be lived with, like rain and snow—the replacement and repair of corroded plant was accepted as regular plant maintenance. Little thought was given to the possibility of preventive measures.

Noppel

The corrosion engineer must be sort of a hydra-headed individual. He must be a technologist, an economist and, in many cases, a salesman.

Training and Skill Needed

As a technologist he must have the training and skill to be able to anticipate and recognize a corrosion problem and how to apply his knowledge to mitigate corrosion and keep it under control.

In planning control programs he must be something of an economist so as to convince management that the costs of the mitigation program will be more than offset by the financial benefits to be attained.

In his third role he must sell his corrosion program to management. Management is interested first, in knowing how much corrosion in a particular situation is costing and, second, how much will be saved by the corrosion control program.

In general, management does not have time and perhaps in some cases the knowledge to analyze a long and detailed technical report or survey. However, management is well equipped to cope with the economic aspects of a company's operations so that, in presenting corrosion mitigation projects to management, it is important that not only the costs of the program be determined but that some estimates can be made of the savings which will be accomplished. The savings effected result in an increase in the net profits of the enterprise.

Design Aids Corrosion Mitigation

In past years the corrosion engineer has been considered by many to be a "doctor." He was to be consulted only in case of trouble similar to the services of a mechanic to whom you took your automobile when you had trouble with the engine. Even today, the real role of the corrosion engineer is not fully understood and too often a plant becomes the responsibility of the corrosion engineer only after it has been built and placed in operation.

Gradually this is changing. With modern techniques as they are being developed, it has been shown that through proper planning and design of new projects, corrosion can be eliminated or, in other cases, reduced to the point where the life of the metallic structure is greatly increased. This can often be done at much lower cost initially than awaiting for corrosive conditions to develop and then trying to correct them.

The buried pipeline is a good example of how the corrosion engineer can function in the design stages of a project. It used to be the practice of some to include a "corrosion allowance" in figuring the wall thickness of a buried pipeline. Today with good coatings and modern methods of applying them and the installation of cathodic protection at the time the line is constructed, this so-called "corrosion allowance" in the wall thickness is no longer considered to be necessary. This represents a substantial saving in steel and on one of the major 1500-mile gas transmission pipelines this saving amounted to some 100,000 tons.

NACE Has Major Role

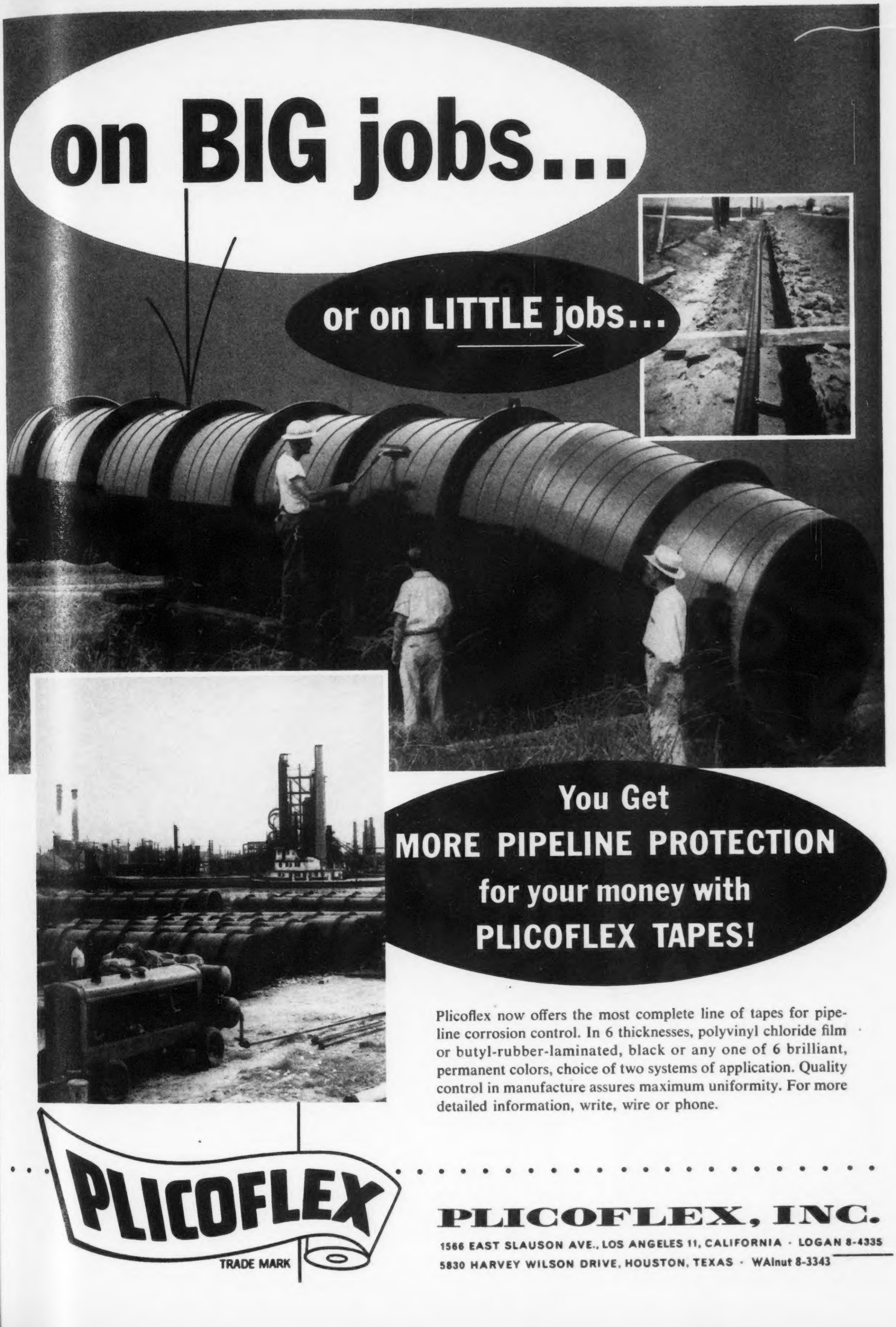
The National Association of Corrosion Engineers through its committees, its meetings, symposiums and publications has played a major part in the improvement of corrosion control methods and techniques. Starting with a relatively small group of men primarily interested in cathodic protection some ten years ago, it has grown to a membership of about 5,000.

When NACE was organized some ten

(Continued on Page 74)

* A luncheon talk at the 1955 Spring meeting, Northeast Region, National Association of Corrosion Engineers, May 11, 1955, New York, N. Y.

Editor's Note: E. P. Noppel, a vice-president of Ebasco Services, Inc., New York, N. Y., is chairman of the NACE Policy and Planning Committee.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Role and Function–

(Continued From Page 72)

years ago, we had five regional divisions and practically no sections. Today we have one additional regional division covering the Dominion of Canada and nearly 50 sections.

Our association of corrosion engineers is organized at all levels of industry. The sections provide for consideration and discussion of a wide range of corrosion problems at the local level. Through the regional meetings, such as you are having this week, provision is made for study and discussion of corrosion problems on a somewhat broader base than the sections.

Through the national association with its annual meeting, its various technical practices committees and the Corrosion magazine, we have provision for consideration of the broad problems of corrosion on a national basis. The corrosion engineer has an opportunity through these varied activities to learn of the major advances in the field of corrosion mitigation.

Technical Committees Important

In discussing the role of the corrosion engineer in industry today it is important to touch briefly upon the activities of the technical committees of NACE. These provide an excellent means to participate in corrosion work. Perhaps in no other place are so much data and experience made known and circulated to interested persons. Technical reports published by the committees are the result of pooled information from a large number of companies covering a wide range of experience.

Corrosion control methods and techniques are being constantly improved. To adequately take his part in American industry, the corrosion engineer must keep abreast of these improved methods and techniques.

NACE through its sectional, regional and national organization offers him this opportunity.

The activities of NACE in the field of corrosion have stimulated interest in different parts of the world. We have received inquiries from Venezuela and Israel as to some form of affiliation. A recent article in a British publication "Corrosion Technology" reviews the steps that are being taken in England to organize a British association similar to our own.

The general public is becoming corrosion conscious. The real estate salesman impresses his customers with remarks about glass-lined hot water tanks protected with a magnesium rod, and brass or copper tubing for the piping system.

The gasoline filling station operator points out the advantages of his anti-freeze radiator compound which contains rust inhibitors to protect the radiator from corrosion.

Interest Is Widespread

The automobile salesman finds it easy to convince purchasers that undercoating their automobile bodies is a good investment. This increasing recognition on the part of the public of the importance of mitigating corrosion causes the manufacturer to pay attention to corrosion control in the design of his products and brings the corrosion engineer into a new range of activity in modern industry.

In industry today the corrosion engineer must be versatile. One example of the varied roles he is called upon to assume is a recent inquiry which came to use in which a duct run carrying electric power cables became infested with black widow spiders. The problem put to the corrosion engineer in this case was: Would DDT or other modern insecticides effectively kill the spiders and, if so, what effect would it have on cable insulations and lead coverings. One of the things we learned is that a spider is not an insect but an arachnid.

We hear a lot today about the importance of site selection for industrial plants. This is a field in which the corrosion engineer can play an important part by conducting soil surveys of various sites under consideration. Many industrial plants involve a large investment in underground piping and other metallic structures.

In past years some plants involving underground piping have been located on cinder fills with the result that extremely high maintenance costs were incurred by pipe replacements necessitated by corrosion.

Corrosion Problems Very Severe

Where metallic structures are located in cinder fills, the corrosion engineer is called upon to cope with an extremely difficult problem. Cathodic protection is not completely effective due to the shielding effects of carbon particles in the cinders contacting the pipe.

We hear daily about atomic energy for peace-time applications. The current rapid development of atomic energy as a heat source in power plants is resulting in many new problems relating to corrosion. I understand the metallurgical and corrosion problems in this field are some of the most difficult ones requiring solution.

There is another important role the corrosion engineer plays in industry and that has to do with the conservation of our natural resources of various metals. Industry cannot afford to overlook the conservation of metals as a national requirement any more than it can afford to be uninterested in its own economic advance.

In conclusion let me point out that NACE is the only association organized on a national basis devoting its activities entirely to problems relating to corrosion. It offers an opportunity through these activities to enhance and increase the importance of the role played by the corrosion engineer in modern industry.

The big problem today is not only the control of corrosion on structures after they are built, but to design against corrosion in every feasible way rather than try to mitigate it at some later date.

Fontana Teaches at Aruba

Mars G. Fontana, chairman of the Department of Metallurgical Engineering, Ohio State University, Columbus, spent the month of June in Aruba in the Netherlands West Indies teaching two corrosion courses to employees of Lago Oil and Transport Co. Dr. Fontana went to the Dominican Republic to do some additional corrosion work after leaving Aruba before moving on to Haiti, Jamaica and back to his home at Columbus. He was accompanied by his family.

Gasoline Plant Corrosion Discussed at Houston

Gasoline Plant Corrosion was the technical subject at the June 14 Houston Section meeting. D. R. Fincher, Tide Water Associated Oil Company was the speaker. Mr. Fincher listed seven causes of gasoline plant corrosion. They are: Dissimilar metals in an electrolyte, absorption by water of acid gases from the hydrocarbon stream, organic acids from producing wells, recirculating cooling water containing oxygen, carbon dioxide absorbed in condensed steam, soils and oxygen.

As an example of money saved by corrosion control, Mr. Fincher told of a 24-mile products line being severely corroded. Ten leaks occurred in 1948, each one costing about $285 for repair plus $1000 lost production. Since 1949, with cathodic protection, there has been only one leak, with about $9000 being spent on the line, less than expenses of walking the line.

Price of Back Issues of Corrosion Is Increased

The price of back issues of Corrosion three or more years old has been increased to $2 a copy by action of the NACE Executive Committee. The price applies to both members and non-members. This means that all available issues published 1945-51 inclusive will cost $2 per copy postpaid.

The usual additional book post registry fee of 65c per package applies to orders addressed to persons outside the United States, Canada and Mexico.

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An annual index to the abstracts published in the Corrosion Abstracts Section is published in December.

General News

Industry Backing Sought For Corrosion Research

The Corrosion Research Council of the Engineering Foundation to be formed with the aid of the American Institute of Mining and Metallurgical Engineers, the Intersociety Corrosion Committee and The Electrochemical Society is expecting financial backing from industry for a research program. The initial aims of the group, are increased fundamental scientific data and close cooperation among scientists in electrochemistry, physical metallurgy, solid-state physics, nuclear physics, surface chemistry and physics and others.

H. N. Uhlig, head of the Massachusetts Institute of Technology's Corrosion Laboratory is head of the organizing committee.

The Engineering Foundation has given grants with no contingency as follows: $3000 for a project on Prevention of Corrosion of Water Pipes and to Research Council on Corrosion, $4000 with a contingency of $30,000.

Committee for Tappi Plastics Meeting Named

J. C. Pullman, American Cyanamid Co., chairman of The American Pulp and Paper Institute's plastic committee has named the committee for the Tappi National Plastics Meeting. With a theme of "Fibers and Plastics for Laminates," the meeting will be held in Brooklyn, N. Y., November 14-15.

Members of the committee are: H. F. Mark, Polytechnic Institute of Brooklyn, general chairman; W. D. Hardy, Foster D. Snell, Inc., technical program chairman; R. Lindenfelser, Amercian Cyanamid Co., local arrangements chairman. V. C. Stannet, New York State College of Forestry, secretary of the plastics committee and Mr. Pullman also are members of the national meetings committee.

European Federation On Corrosion Formed

Thirty-three technical and scientific societies from eight European countries (Germany, France, Italy, Luxemburg, Austria, Sweden, Switzerland, Spain) met during the Convention of Chemical Technology at Frankfurt-am-Main May 19 to discuss the phenomena and causes of corrosion. A federation was formed among the organizations with headquarters in Paris and Frankfurt.

Nine German scientific and technical societies have joined to form the Arbeitgemeinshaft Korrosion with headquarters at Dechema, Frankfurt-am-Main.

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Abstracts published in the NACE Bibliographic Surveys of Corrosion are obtained from more than 28 abstracting agencies.

AISI Announces Changes In Several Steel Classes

The American Iron and Steel Institute has announced changes in the published analyses of the 501 and 502 heat resisting steels and additions to the 300 and 400 series. Six types have undergone changes in maximum allowable carbon content provided for in standard compositions. These are 301, 302, 302B, 316, 317 and 446.

Changes in chemical composition were made in Types 304, 304L, 317, 321, 347 and 405. In Type 321 there has been an increase in nickel content from 8.00/11.00 to 9.00/12.00. Nickel content has been increased for Type 348. Maximum carbon content of Type 446 has been reduced from 0.35 to 0.20.

Types 303Se, 416Se and 430F Se have improved machinability through the addition of selenium.

Titanium Lectures Planned For Practicing Engineers

Lectures on titanium designed for practicing engineers will be given at the New York University College of Engineering September 12-16. Engineers and scientists from industry and members of the NYU faculty will present 25 talks covering, among other topics, phase diagram metallography and alloying, heat treatment and mechanical properties; mechanical metallurgy, analysis, corrosion and fabrication; fabrication and applications. ASM is cooperating in presenting the series. Registration ends August 20.

New Stress-Strain Meter

Impact is described in terms of dynamic stress-strain relationships in a new instrument called the "impact tube." It was developed by the Research Division of the New York University College of Engineering and is described in the June issue of the NYU Engineering Research Review. Copies of the publication are available on request from the Office of Information Service, New York University, University Heights, 53, N. Y.

Packaging Course Set By Stevens Institute

The Industries Training School at Stevens Institute of Technology, Hoboken, N. J. will open a course September 26 on the application of new concepts of packaging and materials handling in production, warehousing and shipping. Topics will include modern techniques pertaining to various kinds of containers, packaging machinery and package testing methods.

Registration ends September 19 for the one-night-a-week courses open to men with high school diplomas.

BOOK REVIEWS

Aluminum Paint and Powder. By Junius D. Edwards and Robert I. Wray, Aluminum Research Laboratories; Alcoa. 6 x 9½ inches, 219-pages, cloth. 1955. Reinhold Publishing Corp., 430 Park Ave., New York 22. Per copy $4.50.

Third edition. Book provides explanation of manufacture, properties and testing of aluminum powder with special emphasis on processes involved, color, brilliance, leafing, density, grading and handling as well as performance data and references. Chapter on aluminum paint composition gives information on varnish, lacquer, silicone resin and bituminous vehicles, grade and amount of aluminum pigment and includes references.

Aluminum research laboratories tests, importance of film thickness, pigment concentrations, comparison with other paints, priming costs for steel and painting aluminum, magnesium, zinc, steel and aluminum alloys for marine service are subjects included in chapter on aluminum paint in protection of metals. Another chapter on special properties and uses of paint describes subjects such as reflectance, visibility, painting interiors and aluminum paint for oil tanks, structures, furnaces and radiators as well as water vapor transfer, resistance to sulfur compounds and electrical conductivity. Book is replete with tables, graphs and illustrations.

Bibliographic Survey of Corrosion, 1950-51. 430 pages, 8½ x 11 inches, cloth. 1955. Compiled by A. Irene Humphrey. National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas. Per copy, members of NACE $10; non-members, $12.50.

The fourth in the series of bibliographies of corrosion literature published by NACE. Abstracts are for articles and books published in the biennium 1950-51. Each article is abstracted with title, names of authors, volume, number of issue, inclusive pages, year of publication and date of issue plus an abstract. Abstracts are from the some 30 agencies that authorize NACE to use their abstracts and range from the indicative to the informative.

The book includes 4454 abstracts, indexes 4047 authors, has cross-indexing after each topical subdivision. Topics are those in the NACE Abstract Filing System Index. There also is a comprehensive alphabetical subject index.

Vapor Plating. 158 pages, 5¾ by 9 inches. 1955. By C. F. Powell, I. E. Campbell and B. W. Gonser. John Wiley & Sons, Inc., 440 Fourth Ave., New York 16, N. Y. Per copy, $5.50.

After a brief historical summary about the vapor deposition process the book opens with a 3-page table listing the metals and alloys used for vapor deposition, with physical characteristics of

(Continued on Page 78)

BOOK REVIEWS

(Continued From Page 77)

each. Coating apparatus is described and characteristics, adhesion and other considerations reviewed and illustrated. Chapter 2 is devoted to a discussion of vapor deposited metals, followed in succeeding chapters by carbides, nitrides, boron, silicides and oxides. References are appended after each chapter.

An author and alphabetical subject index are included.

Report on the Activities of Commission No. 4 for Protection Against Corrosion of ABEM. II. Technical Report. In French. 28 pages, 8⅜ x 10¾ inches. March, 1955. Anonymous. Association Belge Pour L'Etude, L'Essai et L'Emploi des Materiaux, 38, Rue de Naples, Brussels, Belg. Price not indicated.

An illustrated report on the 1954 work done by the Belgian commission for protection against corrosion. Organization of and details concerning the progress of tests of materials in atmospheric, marine and laboratory environments are given. A program of new investigations is outlined and a list of publications issued during 1954 included.

Proceedings. Meeting of Centre Belge D'Etude de la Corrosion. Anonymous. In French. 86 pages, 8¼ x 11¾ inches. April, 1955. Centre Belge D'Etude de la Corrosion, 21 Rue des Drapiers, Brussels, Belg. Price not indicated.

Proceedings of a meeting of Cebelcor held April 13-14, 1955. Reports are given on the progress of the studies being conducted by Cebelcor. Numerous diagrams of data are included illustrating the thermodynamics of the various problems under study.

A list of the publications issued so far by Cebelcor is appended.

Tentative Specifications for Corrosion-Resisting Chromium and Chromium-Nickel Steel Covered Welding Electrodes. 6 x 9, paper. 1955. The American Welding Society, 33 West 39th St., New York 18, N. Y., and the American Society for Testing Materials. Per copy, 40c.

Eight new classes of electrodes are included in this revised edition of specifications. They are two extra low carbon grades; two columbium grades; two molybdenum grades and grades E312 and E318.

Test methods, weld metal composition requirements, standard sizes and lengths and an appendix to aid users in selecting the proper electrode are included.

Tentative Specifications for Low Alloy Steel Arc-Welding Electrodes. 16 pages, 6 x 9, paper. June, 1955. American Welding Society, 33 West 39th St., New York 18, N. Y., and American Society for Testing Materials. Price, per copy, 40c.

Electrodes are classed by chemical analysis in addition to the usual classification by mechanical properties. This will permit user to choose alloys that will provide weld metal of properties and mechanical characteristics which will match basis metal closely in corrosion resistance and otherwise. An appendix provides a useful guide to the understanding and best use of the specification.

Chemical Behavior of Aluminum. 333 pages, 6 x 8¾ inches, cloth. 1955. Anonymous. (In German) Aluminum Verlag GmbH, Jagerhofstrasse 26/29, Dusseldorf, Germany. Price not indicated.

Narrative and tabulated data on the influence of various physical states and the degree to which aluminum is corroded by numerous media. There are 50 pages of tabulated data showing the resistance of the metal versus specific corrosives, and an extensive alphabetical subject index.

28 Papers Scheduled for Industrial X-Ray Meeting

Twenty-eight technical papers are scheduled to be presented August 11-12 during the Fourth Annual Symposium on Industrial Applications of X-ray Analysis. The meeting is sponsored by the Denver Research Institute, University of Denver.

Aluminum Division Formed

An Aluminum Division has been formed within the Porcelain Enamel Institute. Basic aluminum manufacturers and frit manufacturers are interested in the division. Charles P. Lohman of Pemco Corp. has been elected chairman.

•

An annual index to the abstracts published in the Corrosion Abstracts Section is published in December.

NEW PRODUCTS —Materials—Service—Literature

Parker Pre-Enamel 410, a porcelain enamel which requires no ground coat has been developed and tested by Parker Rust Proof Co., in cooperation with Frigidaire Div., General Motors and Pemco Corp., Baltimore, Md.

•

Tube-Kote, Inc., Houston has more than doubled the capacity of its 15-acre plant.

•

PVC Fittings are produced by the injection molding process in a complete line of sizes and shapes for solvent welding by Tube Turns Plastics, Inc., Louisville, Ky.

•

Culligan, Inc., Northbrook, Ill., has developed a plastic coating "Cul-Dur" which it says can materially lengthen the service life of water softeners by reducing corrosion.

•

Alcaloy, an aluminum alloy, is used to make a heavy duty spur geared hoist by the Ohio Hoist and Mfg. Co., Shaker Square, Cleveland 20, Ohio. The metal, besides having the requisite strength, is much lighter, non-magnetic, non-sparking and corrosion resistant, the company says.

•

Vacu-Blast "Waffle" floor sand blast rooms provide true downdraft ventilation for sandblasting operations without excavation and using the blast air to ventilate as well as return the abrasive. It is available from Vacu-Blast Co., Belmont, Cal.

•

Koppers Company has been granted rights to design, construct and license plants to use the L'Azote process for synthesizing ammonia from coke-oven, refinery gas or any other hydrogen source. The low cost method was developed in Belgium.

•

Molded Fiberglass Tray Co., Linesville, Pa., has developed a 17 x 23 x 8-inch tray for use on conveyor belt production lines.

•

International Nickel Co., Inc. has opened its Southeast States Technical Field Section, Development and Research Div., with headquarters at 3179 Maple Drive N. E., Atlanta, Ga.

•

A New Series of corrosion resistant precipitation hardenable stainless steel alloys has been announced by the Research Division of Cooper Alloy Corp., Hillside, N. J. The alloys are designed to meet the following needs: PH55A—High strength, high hardness with fair ductility for erosion and abrasion resistance or for stressed parts in corrosive applications. PH55B—A ductile high strength alloy of medium hardness for shock resistance and high stresses in corrosive applications. PH55C—A very high hardness alloy of low ductility for non-stressed, corrosion resistant parts. PH20—A gall resistant alloy with superior corrosion resistance. All three PH55 alloys are variations of the 19Cr, 9Ni analysis. Corrosion resistance is said to surpass that of Type 316 stainless. Type PH20 is a precipitation hardenable version of 20Cr, 29Ni Type 20 alloy with good resistance to hot sulfuric acid and a long list of corrosive solutions.

S & C Manufacturing Co., 6245 Wiehe Road, Cincinnati 13, Ohio, says its non-corrosive tank outlets made of polyvinyl chloride make a strong connection with PVC pipes and tanks lined with PVC.

•

Minneapolis-Honeywell electronic controls automatically regulate the amount of lime and caustic fed into industrial waste from General Electric's Electric Houseware department at Allentown, Pa. Chart records are kept of the chemical content and rate of flow of wastes into municipal sewers.

•

6066, an aluminum alloy developed by Harvey Aluminum, Torrance, Cal., is used to produce high-strength, weldable and corrosion resistant specialty tubing.

•

Dorber Co., 7741 W. Palatine Ave., Chicago 31, Ill., is making a dissolved oxygen analyzer which automatically translates diffusion current into units of dissolved oxygen. The unit is not subject to interference by dissolved iron, calcium, magnesium, sulfide, nitrites or organic matter, manufacturers claim.

•

Neoprene protective coatings which can be applied directly as received by conventional methods to masonry, wood, metal, fabric or rubber are being pro-

(Continued on Page 80)

NEW PRODUCTS

(Continued From Page 79)

duced by Saran Protective Coatings Co., 2415 Burdette Ave., Ferndale, 20, Mich. They are being produced in four colors. Bulletin No. 103 gives specifications and resistance data.

•

Reflin Co., 5730 Kearny Villa Rd., San Diego, Cal., is making a complete line of plastic pipe fittings for use with Reflin fiber glass thermosetting corrosion service plastic pipe.

•

"M" Treated cotton fiber cloth is resistant to many common chemicals, is highly resistant to mildew, shrinkage and wrinkling, according to National Filter Media Corp., 1717 Dixwell Ave., New Haven 14, Conn.

•

Type BT tubeaxial propeller fans produced by Propellair Div., Robbins & Myers, Inc., Springfield, Ohio, are recommended for handling corrosive exhaust, high temperature or explosive fumes. Propellers are cast from a magnesium-aluminum alloy which has greater corrosion resistance to mild alkalis than usual propeller materials, the company says. Special corrosion resistant coatings can be applied at the factory when specified.

•

Hastelloys B and C have been accepted by American Society of Mechanical Engineers for use in unfired pressure vessels. Specifications covering mechanical properties, fabrication, test procedures and heat treating are discussed in ASME Case No. 1173 for Hastelloy B and Case No. 1194 for Hastelloy C.

•

How Zinc Controls Corrosion, an illustrated 32-page and cover brochure explains the reason for and describes the many uses of zinc for the protection of steel against rust. Copies are available from American Zinc Institute, Inc., 60 East 42nd St., New York 17, N. Y.

•

Stainless Steel Globe valves available from Cooper Alloy Corp., Hillside, N. J., are described and illustrated by engineering drawings of sections in a folder available from Cooper Alloy Corp. Principal uses of major Cooper alloys are tabulated.

•

Centrifugal wet dust collectors for control of hot, moist, corrosive, abrasive or obnoxious dusts are described in a brochure issued by Pangborn Corp., Hagerstown, Md.

•

Dura-Lite, a clear, strong thermoplastic which is basically methacrylate, has improved resistance to chemical attack, crazing and abrasion as a result of additives. This and other plastics are described in a brochure available from The Homalite Corp., Wilmington 166, Del.

•

"B" and "C" corrosion resistant nickel-molybdenum alloys tubing with excellent resistant to hydrochloric acid and general usefulness in halogen acid service are described in a file folder fact sheet available from The Carpenter Steel Company, Alloy Tube Division, Union, N. J. Resistance to corrosives by both grades is described.

•

"Half-Second Butyrate," a flat opening, 42-page, tab indexed brochure of file folder size describes the properties, modifications and applications of this Eastman Chemical Products, Inc., material. It is available to those who formulate and sell lacquers. A wide variety of detailed information on the material is tabulated. Copies can be obtained from the company's Kingsport, Tenn., offices.

•

Monel and Nickel Corrosion Resistant Valves made by Alloy Steel Products Co., Inc., West Elizabeth Ave., Linden, N. J., are described and illustrated in a folder available from the company.

•

Small Sized deaerating heaters for small steam generating plants are described in a technical bulletin available from Graver Water Conditioning Co., 216 West 14th St., New York, N. Y.

•

Tapecoat "X" a single-wrap coal tar tape for pipe which Tapecoat Company, 1523 Lyons St., Evanston, Ill., says provides protection equal to double wrap is now available. Only a ½-inch overlap is required. Greater coverage, easier application and savings in time, in addition to savings in material cost are claimed. It is available in 2, 3, 4 and 6-inch rolls.

•

Titanium and titanium alloy mill products meeting a new O.1 percent maximum carbon content requirement are being produced by Mallory-Sharon Titanium Corp., Niles, Ohio.

•

Polyethylene threaded and sleeve fittings in 1½-inch ID size are made by Arthur S. LaPine & Co., 6001 South Knox Ave., Chicago 29, Ill.

•

Rokide coatings that permit metals to be used at temperatures ranging from 3000 to 3600 F will be applied by Bettinger Corp., Waltham, Mass., under license from the Norton Company.

•

Kucher-Huhn Co., Inc., Philadelphia, manufacturer of mechanical seals for rotating shafts in jet and high temperature equipment has been purchased by Koppers Co., Inc. It will be operated as a Department of the Koppers Metal Products Division.

•

Rotocycle meters made by Rockwell Manufacturing Co., are all bronze. Design is the same as in the company's carbon steel and stainless steel Rotocycles.

•

Pydraul 150 and Pydraul 600 now available in commercial quantities from Monsanto Chemical Company's Organic Chemicals Division for use in hydraulic systems. They have the same non-corrosive characteristics as Pydraul F-9. The fluids differ from older materials in viscosity.

•

Chempro ring packing, jacketed gaskets and molded and machined Teflon parts are described respectively in Bulletins CP552, CP553 and CP554. Copies of the bulletins are available on request from Chemical and Power Products, Inc., 11 Broadway, New York 4, N. Y.

•

Non-Destructive testing will be done in a reorganized department of Sam Tour, Inc., 44 Trinity Place, New York 6, N. Y. Radiographic, ultrasonic, magnetic particle, fluorescent and dye penetrant methods will be used in the field and laboratory.

Chemical Exposition Set

The Ninth National Chemical Exposition will be held in Cleveland November 27-30, 1956.

Nuclear Engineering Session

Nearly 300 papers in 50 sessions are scheduled during the December 12-16 Nuclear Engineering and Science Congress in Cleveland.

•

Four Bibliographic Surveys of Corrosion have been published by NACE covering literature published in the years 1945-51 inclusive.

PERSONALS

R. P. Lee has been named senior engineer and is in charge of corrosion and materials engineering in the Development and Engineering Department of National Lead Co., Titanium Div., South Amboy, N. J.

Chester M. Lewis, Chief Librarian of the *New York Times* has been installed as president of the Special Libraries Association at its annual business meeting June 16 in Detroit.

John R. Hopkins has been named assistant manager of the Southern District sales office of Becco Chemical Div., Food Machinery and Chemical Company in Charlotte, N. C.

Wallace E. Nyce, manufacturing manager, Exide Industrial Division of The Electric Storage Battery Co., retired June 30 after 43 years with the company.

Raymond H. Higgons has been appointed sales engineer with Portland Copper and Tanks Works, South Portland, Me.

David Burnett Scott, Western sales manager for American Potash and Chemical Corp., until his retirement in 1952 died of a heart attack June 20 at Altadena, Cal.

Ralph P. Hudson has been appointed chief of the Cryogenic Physics Section of the Heat and Power Division of the National Bureau of Standards.

Adm. Alan G. Kirk has been elected president of Alloy Precision Castings Co., Cleveland. **Frank W. Glaser** has been named general manager of Alloy.

Harry A. Burdoff, vice-president of the Lunkenheimer Corp., Cincinnati, has retired after 50 years with the company.

J. Richard Milliken has joined the Metallurgical Development Div., Climax Molybdenum Co., as a specialist in process industries and petroleum refining.

Harry L. Smith, Jr., has been elected a vice-president of Aluminum Company of America. He will direct the company's New Kensington and Cleveland Sales development divisions and the company's division of commercial research.

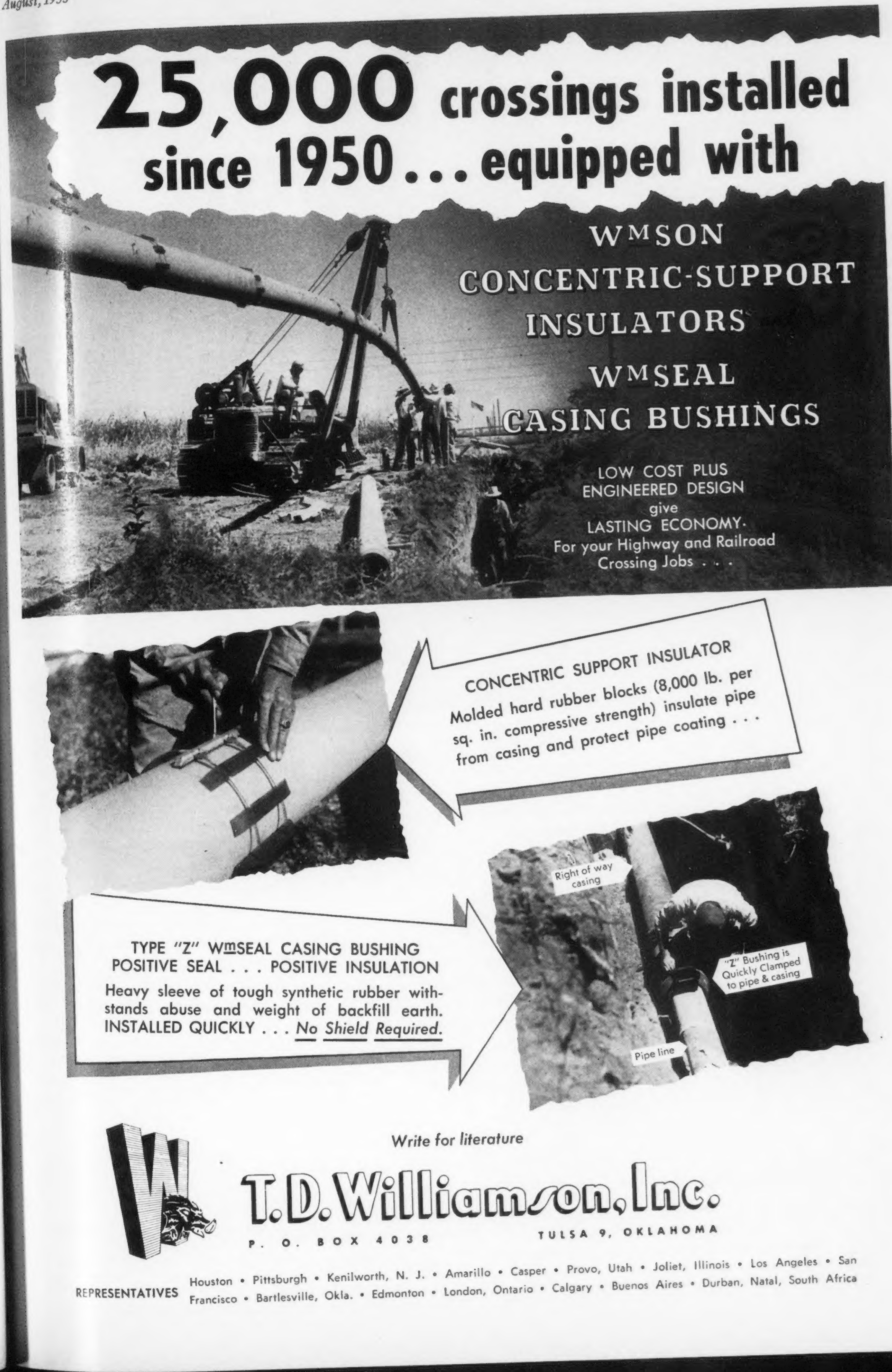
Sidney V. Smith, formerly Industrial Sales Manager, has been promoted to the newly created position of General Sales Manager of Napko Paint Co., Houston. **Ben Russell,** sales engineer, has been put in charge of the company's Dallas regional office.

Everett P. Partridge, Director, Hall Laboratories, Inc., Pittsburgh, has been given the second Max Hecht Award by the American Society for Testing Materials. The award is given in recognition of outstanding service to the committee in the advancement of study of water as an engineering material.

Albert E. Amorosi has been named chief chemist of Alox Corp., Niagara Falls, New York.

Hamilton Gray, professor of civil en-

(Continued on Page 84)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PERSONALS

(Continued From Page 82)

gineering at the University of Maine has been given the chairmanship with the rank of professor in the department of civil engineering in the College of Engineering at Ohio State University. He will assume his duties October 1.

William P. Drake succeeded George B. Beitzel as president of Pennsylvania Salt Manufacturing Co. July 1. Mr. Beitzel will continue as a member of the board and as chairman of the board of Pennsalt International Corp.

C. Roger Sutton, senior metallurgist at the Argonne National Laboratory for the past 5 years has joined the Development and Research Division of The International Nickel Co., Inc., as a member of the Stainless Steel and Heat Resistant Alloys Section.

Dr. Murray Hauptschein, director of Organic Research at Temple University, has joined Pennsylvania Salt Manufacturing Company's research and development staff as senior research chemist. He will specialize in organic fluorine chemistry.

George C. Betz has been appointed manager of sales, Chemicals and Metals Dept., Metal & Thermit Corp., New York. **Henry Mahlstedt** has been named manager of sales of United Chromium Division, Metal & Thermit Corp.

Frank F. Elliott has become president of Crane Co., Chicago.

D. R. Tacke, formerly project engineer, has been promoted to chief of development, Temco Aircraft Corp., Dallas.

Samuel Zerfoss, a physical chemist, has joined Mineral Products Division of the National Bureau of Standards to engage in research in chemical reactions at high temperature.

Joseph R. McClernon, in the charge of International Paint Company, Inc. Interlux Division for 25 years, has been named manager of a Southeastern Division of the company with headquarters at Daytona, Fla. The office of New York salesmanager vacated by Mr. McClernon will be filled by **George Carlin,** who for 17 years was assistant salesmanager.

Carl F. Freeman has been made executive vice president of American Agile Corp., Maple Heights, Ohio.

James J. Reynolds has been named vice president-operations of Alco Products, Inc.

J. E. Stareck has been appointed Director of Research of Metal & Thermit Corp. H. D. McLeese has been named general sales manager of the company.

Frank Jardine, a pioneer in automotive applications of aluminum has retired from his position as technical consultant to Aluminum Company of America. He is a veteran of 37 years' service with the company.

Report on Investigation of Titanium-Nitric Acid Explosion

Probers Say Friction Triggered Ignition of Pyrophoric Material

Introduction

THE CHEMICAL Corrosion Laboratory at the College Park, Maryland, Station of the Federal Bureau of Mines was rocked by an explosion on December 29, 1953. The accident occurred while Walter L. Acherman, chemist, was performing a routine manipulation during a corrosion experiment involving commercially pure titanium and red-fuming nitric acid. There was a sudden and very violent reaction and a large quantity of acid was thrown over Mr. Acherman, causing serious injury.

L. B. Golden, chief of the Chemical Corrosion Section, was exposed to nitric acid fumes during the ensuing rescue operations and died on January 25, 1954. According to the medical report, the direct cause of Mr. Golden's death was pulmonary edema and confluent bronchopneumonia; the contributory cause was inhalation of fumes from red fuming nitric acid.

At the time of the accident, Mr. Acherman was working on a group of corrosion tests involving 118 titanium specimens and approximately seven liters of red fuming nitric acid. The specimens were in 24 Erlenmeyer flasks equipped with stopcocks. The flasks were placed side by side in two heavy pyrex glass trays (18 x 12 x 2⅞ inches) in a fume hood. The flasks were never more than one-half inch apart in the trays and in some instances may have been in contact. Although no appreciable pressure was noted, it was routine procedure in these tests to vent the flasks to the atmosphere at 24-hour intervals by means of the stopcocks to make sure that no great pressure buildup would occur. Mr. Acherman was engaged in this task when the accident occurred. He was wearing rubber gloves but no goggles. At the beginning of this particular experiment he had worn both of these safety devices but had discontinued the use of goggles after several days during which no unusual pressures were noted in the flasks.

The flasks were in the hood just outside the balance room, adjacent to the floor fan. Apparently Mr. Acherman had just touched one of the flasks when a violent reaction occurred, accompanied by a loud noise. Almost all of the glassware, including the heavy trays, was broken.

Acid was thrown over Mr. Acherman's face and body, over equipment and on the floor to a distance of more than 10 feet from the hood opening. The force generated was sufficient to throw at least one specimen, weighing about eight grams, 20 feet; only a trace of acid was found on the rear face of the hood. The laboratory was quickly filled with heavy brown nitric acid fumes. Mr. Acherman was blinded and immediately began to feel intense pain. He managed to reach a sink on the left side of the room but was unable to help himself further. He stated later that he fell to the floor before reaching the sink. However, Miss Campbell, the only witness to the accident, stated that she heard a click just before she heard the loud noise and that Mr. Acherman staggered back from the hood but did not fall to the floor. This discrepancy may arise from the fact that Mr. Acherman, in moving back from the hood opening, came in contact with the bench located in front of the hood, wet his elbows with the acid just thrown there by the reaction and received the impression of being on the floor.

Persons who heard the noise of the accident compared the sound to a muffled thud, to the breaking of a glass tube, or to a shotgun blast. Six men working in nearby laboratories rushed in to render first aid.Two men led Mr. Acherman from the sink to the vicinity of a second sink and the shower. As the shower chain was pulled off in the excitement, a hose in the sink was used to flush the victim, particularly about the eyes and head. A few seconds later a second hose was put into play from an adjacent sink; this was used for flushing the lower half of the victim's body. At 3:58 p.m. Mr. Acherman was taken to a local hospital.

While some of the men attended the victim others opened the windows of the building, started the ventilating fans and brought in additional fans to clear the atmosphere. Sodium carbonate and sodium bicarbonate were spread over the woodwork to neutralize the acid. There was no fire. During these operations several persons in addition to L. B. Golden were exposed to nitric acid fumes by inhalation. At present, however, Mr. Golden is the only person definitely known to have been seriously affected by the nitric-acid fumes.

Summary of Corrosion Tests

Tests Carried Out Before December 1953

The Chemical Corrosion Section is part of the Physical Metallurgy Branch, Metallurgical Division, Region VIII, and has as its specific function the study of the chemical corrosion behavior of metals with a view toward evaluating these metals as materials of construction. The emphasis since organization of this group about eight years ago has been on titanium and zirconium and alloys of these metals. A wide variety of corrosion media has been used.

Reports and laboratory records show that the study of the corrosion properties of titanium in red fuming nitric acid (hereinafter referred to as RFNA) was initiated in the laboratory in April 1948 and that experiments were carried out on four separate occasions before June 30, 1950. The work was done in loosely covered vessels, usually at room temperature, with acid containing 92 percent nitric acid, 6½ percent NO_2, and 1½ percent water. The titanium specimens were cut from sheet rolled from bars consolidated by powder metallurgy techniques. The sheet contained 0.04 percent carbon, 0.10 percent iron, and small amounts of various other impurities. Some specimens were annealed before immersion, others were used in the cold-rolled condition. All specimens were uniformly surfaced. Corrosion rates obtained in these tests varied from 0.02 to 0.26 mil per year (mpy) and the titanium specimens showed no visible signs of attack except an occasional slight discoloration. Between 1948 and 1951 there were also many experiments in which specimens of zirconium alloys were exposed to FRNA. Few, if any tests, were done with titanium in RFNA during 1951 and 1952.

Stress Corrosion Tests Included

Work with titanium in RFNA was resumed early in 1953 and circumstances indicate that at least some of the acid used during this period contained 20 percent dissolved NO_2. The program included stress-corrosion tests of zirconium, titanium, and titanium alloys and evaluation of titanium arc welds and spot welds.

Four groups of 30-day tests designed to evaluate spot-welded titanium in RFNA were completed before December 1953. All of these tests were carried out at room temperature in vessels containing single specimens of titanium and about 250 ml. of nonaerated, quiescent acid. Specimens were cut from commercially pure, 20 percent, cold-rolled titanium sheet made from sponge by arc melting. Some specimens were annealed after spotwelding. Specimens were degreased but not surfaced before immersion in the acid. Specimens in groups 1, 2 and 4 were of a brand of unalloyed titanium (yield strength 75,000 psi) containing 0.15 percent iron and 0.06 percent carbon. Group 3 included specimens of titanium (yield strength 55,000 psi) from another manufacturer; this contained 0.21 percent iron and 0.04 percent carbon.

The first three groups of experiments were done in loosely covered vessels, but the last group was carried out in tightly sealed bottles. In the first group of tests the average corrosion rate was 2 mpy; there was stress-corrosion cracking around the perimeters of the spot welds and large losses in shear strength.

In the next group of tests the average corrosion rates were only 0.03 mpy for annealed specimens and 0.13 mpy for unannealed specimens; there was no loss of shear strength and no sign of cracking.

The average corrosion rates for the third group of tests were 0.03 mpy for annealed specimens and 0.72 for unannealed specimens. Again there was no loss of shear strength and no cracking.

In the fourth group of tests the average corrosion rate was 6 mpy. There was stress corrosion cracking around the perimeters of the spot welds and severe intergranular corrosion and general embrittlement throughout the specimen. Shear strength could not be determined because the specimens usually broke at points away from the spot welds.

Tests Involved in Accident

These tests were planned to determine the effects of such factors as cold rolling, annealing and composition on the resistance of spot-welded titanium specimens to RFNA. The criteria were to be changes in weight, the occurrence of stress corrosion cracking around the perimeter of the spot weld, changes in shear strength of the spot weld, and general embrittlement.

The spot-welded specimens used in

(Continued on Page 88)

★ Abridged from "Investigation of Accident Involving Titanium and Red Fuming Nitric Acid, December 29, 1953," Bureau of Mines Information Circular 7711, U. S. Dept. of Interior, March, 1955. Authors: P. M. Ambrose, Chief, Metallurgical Div., Reg. VIII; J. C. Barrett, Chief, Physical Metallurgy Branch; R. W. Huber, Chief, Metals and Alloys Section; David Schlain, Galvanic Corrosion Section; V. C. Petersen, Metallurgist, Bureau of Mines, all of College Park, Md.

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KEL-F Plastic Molded and Fabricated Valve Linings, Valve Diaphragms, Gaskets, Ring Seals, Gauge Crystals, KEL-F Dispersion Coated or Laminated Lined Tanks, Vessels, Reactors, Piping and Tubing can protect your plant equipment against chemical corrosion

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Report on Investigation–

(Continued From Page 86)

these tests were prepared from commercially pure titanium (55,000 psi yield strength) from manufacturer A. The parent metal contained 0.4 percent iron, 0.2, carbon, 0.02, manganese, 0.02, nitrogen, and 0.005, magnesium. The sheet stock was approximately 0.040 inch thick and each specimen consisted of two 2 by ⅝-inch pieces of metal spot welded together with ⅝-inch overlap. There were 11 groups of spot-welded specimens of 10 specimens each. Each group was treated according to one of the following procedures: Cold rolled to a reduction in thickness of 10, 20, 30, 40 or 50 percent and spot welded; cold rolled 10, 20, 30, 40 or 50 percent spot welded, and annealed; hot rolled 50 percent at 1,200 F. and spot welded.

To make it possible to correlate the results of these experiments with earlier data, eight unwelded specimens of 75,000 psi yield strength material from manufacturer B were included. This material contained 0.05 percent carbon, and 0.1 percent iron, and the same percentages of the other elements mentioned above. Half of these specimens were cold rolled, and the other half were cold rolled and annealed in vacuum at 800 C. All specimens of both types had sheared edges and some also had rolled edges. The specimens were degreased and weighed before being immersed in acid. Spot-welded specimens were immersed in 300 ml Erlenmeyer flasks equipped with stoppers with ground glass joints and stopcocks. The stopcocks were lubricated with a silicone stopcock grease; the ground-glass flask joints were not lubricated. Five specimens were placed in each flask with about 290 ml of RFNA, enough to cover all specimens with at least one-fourth inch of solution. This left approximately 50 ml of void space in each flask and joint. The position of the specimens in the flasks may be described as approximately vertical or at small angles from the vertical. The single specimens were placed in similar 250 ml flasks, four specimens per vessel.

Tests with 108 spot-welded and single titanium specimens were begun between 1 and 4 pm on December 22. The remaining 10 specimens, spot-welded, hot-rolled titanium sheet, were immersed in two flasks at 1:45 pm on December 28. The 22 flasks, containing 108 specimens, were vented daily for six days before December 29. The remaining two flasks started on December 28, were not vented before December 29.

Evidently the corrosion processes, which took place between December 22 and 29, yielded pyrophoric material (probably finely divided titanium) on certain titanium specimens. Some of this material was disturbed by Mr. Acherman as he vented the flasks, and a rapid reaction with RFNA followed. A large amount of heat was liberated, resulting in oxidation and even fusion of metal. Perhaps the shock displaced pyrophoric material on other specimens, causing more reaction and liberation of more heat.

Members of the Physical Metallurgy Branch at College Park made an exhaustic study of the titanium specimens involved in the accident. The specimens of low-yield-strength material showed much higher weight losses than titanium had ever shown before in this corrodent. Specimens were attacked in various ways and at several points, depending on their preimmersion history, but all specimens were attacked. There was much evidence of the formation and spattering of molten metal, especially at sheared edges. Specimens of the high-yield-strength material did not undergo large weight losses but did show signs of extensive intergranular corrosion.

Reports on Tests in Other Laboratories

During the second half of 1953 notes appeared in Metal Progress and in several suppliers' publications to the effect that violent reactions had occurred in several instances when a titanium-manganese alloy had been immersed in RFNA. One of these incidents is known to have occurred in the laboratories of the North American Aviation Co. at Downey, Cal., when several test specimens of a titanium—8 percent manganese alloy reacted with RFNA, showering a chemist with corrosive liquid. The specimens were attacked and pitted and there was evidence of fused material. Commercially pure titanium in the same test was unattacked, giving rise to the theory that the presence of manganese was necessary for reaction and that no trouble would ensue from the combination of commercially pure titanium and RFNA.

Behavior of Titanium in RFNA

Data on the behavior of commercially pure titanium in RFNA, summarized above and in the appendix, are inconsistent. Titanium was almost inert in tests carried out from 1948 to 1950 but was attacked by this acid in many instances during 1953. Such attack was evidenced in one or more of the following ways: Changes in weight, cracking at the spot weld, intergranular corrosion and general embrittlement and formation of pyrophoric material followed by violent chemical reaction. The only occasion when pyrophoric material is known to have formed and reacted on commercially pure titanium was at College Park on December 29. There is no completely satisfactory explanation for this solitary occurrence. However, a review of all available information suggests that certain conditions may have had an important part in the phenomenon. These ideas are presented below in the hope that they may serve as a basis for safety measures or for planning future experiments in this field.

The presence of relatively large amounts of iron and carbon as impurities in titanium may be important in the formation of pyrophoric material. Those specimens heavily involved in the violent reaction of December 29, as shown by large weight losses and the presence of oxidized or fused metal, contained unusually high percentages of iron and carbon. On the other hand, specimens that were relatively low in iron and carbon never exhibited a tendency to react violently, although they have undergone sizable weight losses and have shown signs of intergranular corrosion and general embrittlement. Moreover, the manganese content of all specimens concerned is low, indicating that the presence of manganese is not necessary for forming pyrophoric material and subsequent reactions.

Stresses seem to increase the tendency for titanium to corrode in RFNA but may or may not be important in forming pyrophoric material. Special stress-corrosion tests indicated that titanium and some of its alloys are susceptible to cracking in RFNA, but there was no evidence of unusual reactivity. Fused and oxidized material seemed to be concentrated at the sheared edges of those specimens from the tests of December 22-29 that were cold rolled and not stress relieved. On the other hand, fused metal was also detected in pits on the flat surfaces of specimens that were annealed. The hot-rolled specimens had the highest corrosion rate and this corrosion was largely at the sheared edges. Cracking in the spot-weld area was common, but there was virtually no evidence of molten metal.

The composition of the RFNA may be important. Titanium was resistant in early tests with acid containing 92 percent nitric acid, 6.5 percent nitrogen dioxide, and 1.5 percent water. However, this work is not comparable to the work of 1953 because the tests at that time were all made in loosely covered vessels with titanium specimens that were very low in iron and carbon and had milled edges and abraded surfaces. The behavior of titanium varied greatly in tests during 1953. The acid used in at least some of these tests contained 20 percent nitrogen dioxide.

Certain features of the experimental method may also be important. In this laboratory, sealed vessels were used with RFNA in only two groups of tests. On the first occasion, 10 specimens of 75,000 psi yield-strength material underwent very severe intergranular corrosion and embrittlement. The accident of December 29 occurred the second time sealed bottles were used. The omission of surfacing in preparing specimens and the use of hot-rolled sheet may be significant because it resulted in large, inactive, oxidized surfaces in contact with small, active, sheared edges. Finally, immersion of five specimens in each of 22 flasks with relatively small volumes of corrodent and frequent contact between specimens may have some bearing on what happened.

Causes of the Accident

The causes of the accident have not been determined. The conclusions reached are:

1. Mechanical movement of the equipment probably initiated the chain of events that resulted in the accident.
2. The greatest concentration of corrosion at the sheared edges of the specimens examined occurred when the metal was hot rolled and sheared. This may have been caused by electrochemical effects between the active sheared edges and the relatively inert oxidized surfaces.
3. Two grades of titanium were involved in the test; both suffered corrosion. The grade containing the higher percentages of iron and carbon showed the greater corrosion. The function of either or both of these elements in producing an unsafe condition in RFNA is uncertain; however, the loss of iron in badly corroded areas indicates that the high iron may be a factor worth considering.
4. Metallographic studies show intergranular corrosion in all stress-corroded areas in unannealed samples and in the pitted surface areas of annealed samples. Intergranular corrosion might cause the generation of powdered metal, which is pyrophoric. Deep fissuring and loss of molten material at sheared edges indicate that this type of stress corrosion was a major source of pyrophoric material.

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5. Metallographic studies showed oxidation and in some instances fusion of corroded material. This indicates that considerable heat was generated, which might have been caused by a rapid reaction between pyrophoric material produced by corrosion processes and RFNA.
6. There is no clear evidence that the spot welds of themselves had any part in bringing about the explosion.
7. The possibility of formation of an explosive decomposition product of RFNA, such as hydrazoic acid, should not be ignored. Proof of the existence of such a product, however, is not possible at present.

Recommendations

The following recommendations are made regarding the cause of the accident:

1. The mechanism of this particular occurrence should be determined more positively and others interested in the uses of titanium should be informed of the results. A research program is in progress in cooperation with industry to detetrmine the characteristics of the metal and its alloys in RFNA. Depending on the results of such research, the program might well be expanded or continued to include other reactions.
2. Until this information becomes available, it is recommended that any contact of titanium or its alloys with RFNA or other strong oxidizing liquids be considered potentially dangerous from the explosion standpoint and that proper precautions be taken at all times.

Recommendations for protection of personnel conducting the investigation are:

1. Written operating instruction shall be prepared to include specific safety precautions for any corrosion tests with potentially dangerous materials and shall include the following:

a. All of the operations shall be performed in an acid hood with the vacuum system in operation or in an isolated area where the specimens and acid may be handled by remote control.

b. At least minimum personal protection shall be used, including face shield or goggles and working behind protective barrier, laboratory apron or laboratory coat and polyethylene gloves (rubber or neoprene gloves are not recommended for RFNA).

2. Properly working portective respiratory devices shall be available at all times, and the men shall be trained in the use of these devices. An All Service gas mask with All Service canister is preferable.
3. Properly functioning emergency showers shall be available at all times.

Appendix — Metallurgical Investigation Into the Cause of Explosion

Specimens Involved

The following series of samples figured in the test under way when the explosion occurred:

a) Unalloyed titanium (yield strength 55,000 psi) from manufacturer A, cold rolled 10, 20, 30, 40 and 50 percent, and spot welded. Ten samples for each percentage of cold roll.

b) Same as a) except all samples were vacuum annealed at 800 C after spot welding.

c) Same material as in a) and b), warm rolled 50 percent at 1200 F and spot welded. Ten samples.

d) Unalloyed titanium (yield strength, 75,000 psi) from manufacturer B, as cold rolled. Four samples.

e) Same as d), except samples were vacuum annealed at 800 C.

Sample series a) represents stress by various degrees of cold rolling, whereas sample series c) was stressed by warm rolling. The stresses set up on the edge of the sample by shearing were not considered at the time. Aside from these objectives, control samples were prepared to run more or less concurrently. Series b) samples were run to check the influence of post annealing on spot weld attack. Series d) and e) samples represent titanium strip obtained from a different source and hence of different composition, in the cold-rolled and annealed condition, respectively.

The conditions of the experiment were to submerge the samples in RFNA for 30 days at room temperature under static, nonaerated conditions at atmospheric pressure or slightly above. Twenty-four Erlenmeyer flasks (250 cc) were used, each flask containing five titanium samples. The flasks had ground glass joints with stopcocks to keep the samples nonaerated and to make it possible to relieve pressure buildup by venting the flasks daily. No pressure buildup was noted at the moment of the explosion, at which instant the chemist in charge had finished venting a flask.

The spot-welded samples of 0.041-inch thick stock were approximately ⅝ inch wide by 3½ inches long. Series d) and e) samples, also 0.041 inch thick, were cut ⅝ inch wide by 2 inches long. All samples, except those of series c), ran 7.11 days; those of series c) received only one day exposure before the explosion.

Since the explosion shattered the flasks and scattered the samples, the only means of identification was scribe markings on the individual samples, which in many instances were corroded away. Of the 118 samples under test, 99 were identified, 15 were corroded beyond identification and four were lost. All the unidentified samples were of series b); this group had received a high degree of surface pitting.

Corrosion Test Results

Preliminary examination of the samples revealed several types of corrosion, some of which were unique to this experiment. It was considered advisable to determine not only the corrosion rate for each sample based on loss in weight but also to establish definitive standards (types) of corrosive attack and to catalog each sample as to the severity of each corrosion form. Accordingly, photo-

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Figure 1A—Surface staining attack in a cold-rolled series (d) sample. 4X.

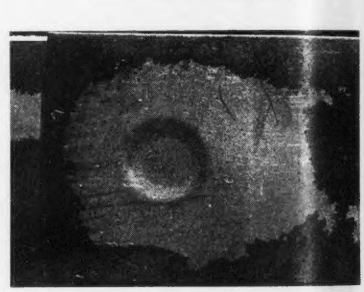

Figure 1B—Staining attack in cold-rolled, spot-welded titanium from the same heat as Figure 1A exposed to RFNA for 30 days in an earlier run. 2X.

Figure 2—Surface pitting attack observed in annealed series b) spot welds. Arrow at X indicates pits unaltered by the explosion. Pits at Y were oxidized during the explosion. 4X.

Workmen apply "SCOTCHRAP" Brand Pipe Insulation to the outer column of a 200-foot-deep well column.

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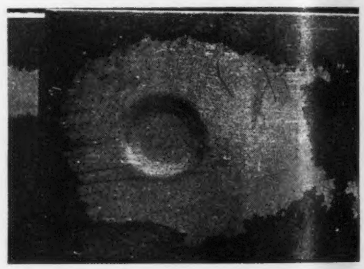

Figure 1B—Staining attack in cold-rolled, spot-welded titanium from the same heat as Figure 1A exposed to RFNA for 30 days in an earlier run. 2X.

Figure 2—Surface pitting attack observed in annealed series b) spot welds. Arrow at X indicates pits unaltered by the explosion. Pits at Y were oxidized during the explosion. 4X.

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micrographs were made of representative corrosion forms. These are presented in figures 1-7B for further reference. Four general types of attack were observed, namely:

1. Staining (dark gray to blue).
2. Pitting.
3. General attack.
4. Stress-corrosion cracking:
   a) At spot-weld indentation.
   b) At rolled edges (some samples possessed edges from the original as-rolled sheet).
   c) At sheared edges.

Staining attack (note Figure 1A) was confined to the series d) samples. Figure 1B is a spot-welded titanium strip from manufacturer B exposed to RFNA for 30 days in a previous experiment in November 1953. The same staining is observed here in a more pronounced stage, owing to the longer exposure time.

Pitting attack was observed in the a), b) and e) sample series. It was accompanied by dark-gray staining around the pit edges (note Figure 2, arrow X), except in those pits where ignition occurred during the course of the explosion resulting in oxidation. The latter pits showed oxidation of both the pitted and stained area. The oxidation products are identified by a prismatic array of color which photographed gray (note Figure 2, arrow Y).

General attack is illustrated in Figure 3. It appeared only in the annealed samples (that is, series b) and e)). This attack is actually an advanced form of pitting where the entire area has become pitted and the metal has been etched deeply enough to reveal the rolling texture.

Three forms of stress-corrosion cracking are seen in Figures 4-7B. In spot welds the stress corrosion cracking followed the periphery of the indentation (note Figure 4). Two views of stress cracking at a rolled edge are observed in Figures 5 and 6. The stress corrosion is observed in Figure 5 to propagate in a tree pattern from the rolled edges. Stress attack at sheared edges is illustrated in Figures 7A and 7B. Here edge views of samples with different degrees of attack are shown.

At the sheared edges corrosion was deep, and oxidation of disintegrated material generated enough heat to cause melting and spatter. These features are seen in Figures 7A and 7B. Since the samples were overlapping in the nitric-acid solution, expulsion of molten material from corrosion fissures along the sheared edges was found in several cases to have spattered on the underlying sample, thus outlining the region of overlap (note Figure 8). In Figure 6 some expulsion of molten material is noted from a transverse crack at a rolled edge. Only minor amounts of spatter were observed emanating from the cracks at spot indentations.

A detailed study was made of all samples recovered from the explosion to determine to what extent each sample series a), b), c), d) and e) underwent the various forms of corrosive attack discussed under corrosion types. Of equal concern was the degree of oxidation of the corroded products, since this information would indicate the test group or test procedure contributing most to the severity of the explosion. Test results are tabulated in Table 1.

The highest corrosion rate (115.5 mpy) is observed in the warm-rolled, spot-weld group, series c) and occurred almost exclusively at the sheared edges. Since this series ran only one day, the results cannot be used for comparison purposes; nevertheless, it is significant to note that the gullying and fusion at the sheared edges were almost as severe in these samples as they were in those of series a), exposed 7.11 days.

Edge attack likewise accounted for a major portion of the attack in the series a) sample group. It is observed that the 20 and 30 percent cold-roll samples had the highest attack in all of the corrosion forms tabulated, with a falling off at greater and lower percentages of cold work.

Corrosion weight loss in the annealed spot welds, series b), is credited largely to extensive surface pitting attack—several times greater than for the corresponding cold-rolled samples. No localized attack at the sheared edges or spotweld area was observed in either of the annealed series b) or e), indicating total absence of stress-corrosion attack.

The surface attack on the annealed material from manufacturer B, sample series e), covered the same surface area (that is, 50 percent) as the average attack on the corresponding material from

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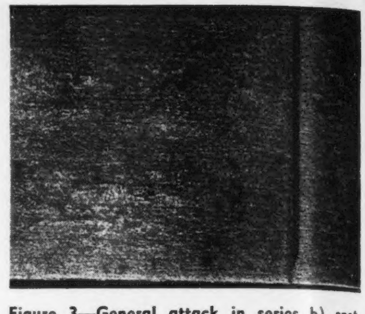

Figure 3—General attack in series b) spot-weld samples. This is an advanced form of the pitting attack observed in Figure 2. 2X.

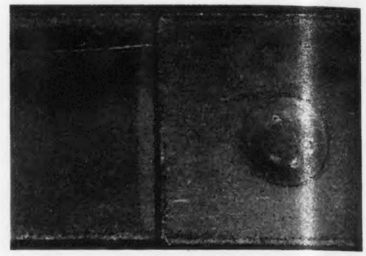

Figure 4—Stress-corrosion cracking along periphery of spot-weld indentation observed in unannealed series a) and c) samples. 3X.

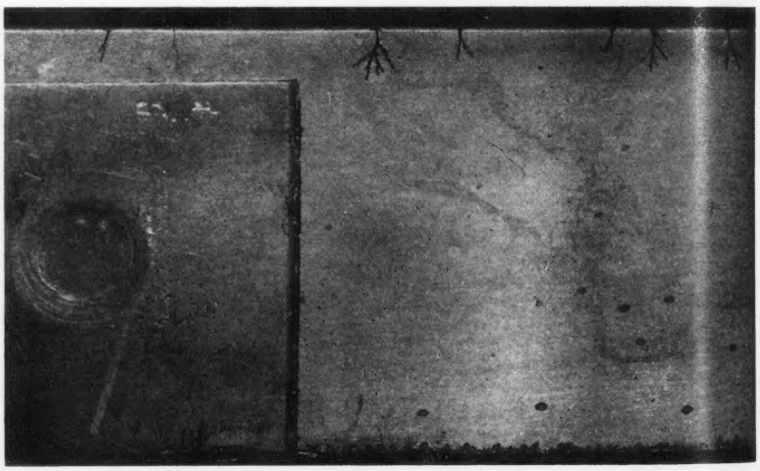

Figure 5—Stress corrosion cracking propagating in a tree-like pattern from rolled edge at top. Bottom edge is sheared. 4X.

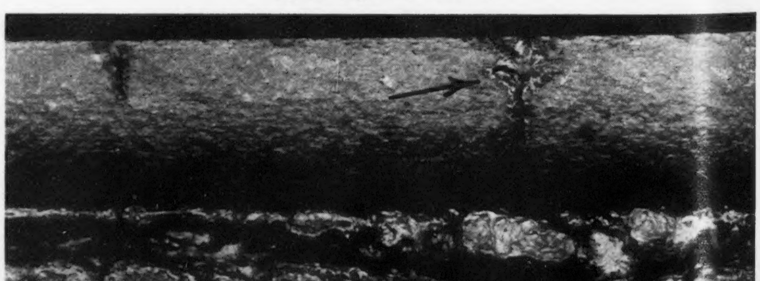

Figure 6—Edge view of stress corrosion at rolled edge. Arrow indicates expulsion of molten material. The rolled edge sample was spot welded to a sheared edge sample seen in lower half of field. 25X.

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manufacturer A sample series b). This similarity of attack was not found in the cold-rolled samples. Here the cold-rolled series d) samples showed a staining type of surface attack, whereas the corresponding series a) material exhibited a pitted type of surface attack.

Differences in composition in the two sample sources will be discussed in the paragraphs on analytical studies. Suffice it to say here that the explosion apparently did not originate in the samples of the d) and e) series, since no evidence of oxidation was observed here.

Metallographic Studies

Selected metallographic sections of corroded and fused areas were examined to determine the nature of corrosion propagation.

In the study of the behavior of staining attack, as illustrated in Figures 1A and 1B, an isolated stain patch was selected

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Figure 7A—Edge view of spot welded samples with sheared edge attack. 25X.

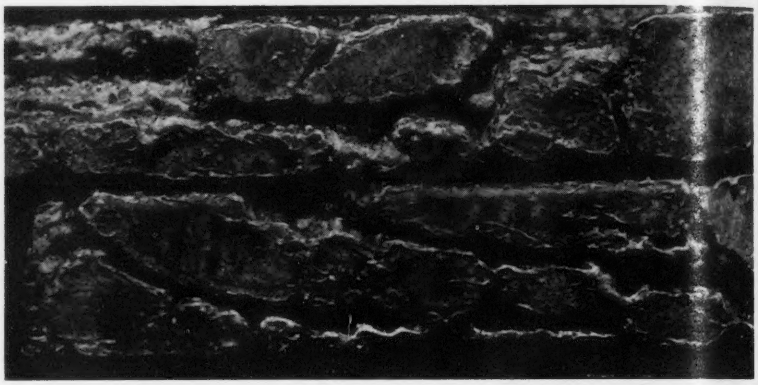

Figure 7B—Same as 7A but showing a more advanced attack. 25X.

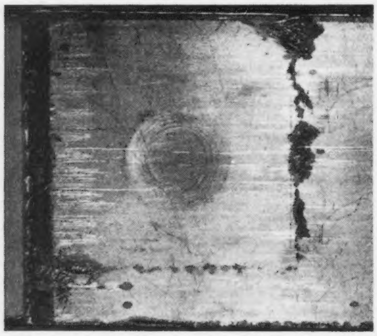

Figure 8—Spatter from sheared edge of overlying sample outlining the region of overlap. 3X.

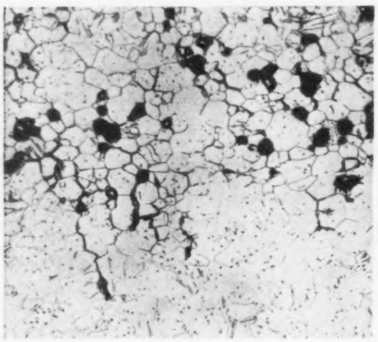

Figure 9—Micrograph of structure underlying stained area at arrow in Figure 1A. Top portion of field underlying stained area shows intergranular attack. Keller's etch. 66X.

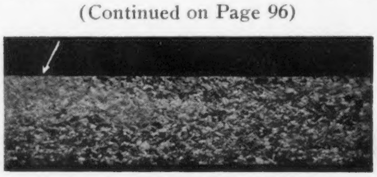

Figure 10—Section through stained and unattacked surface seen in Figure 1B. Arrow indicates unattacked (unstained) surface. Keller's etch. 13X.

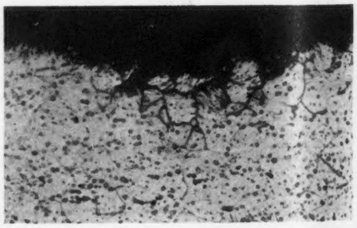

Figure 11—Transverse section through unignited pit in annealed series b) sample. Attack is seen to be intergranular. Keller's etch. 87X.

TABLE 1—Test Results (Sample Series)

	FROM MANUFACTURER A										FROM MANUFACTURER B		
	(a) Cold-rolled, percent					(b) Cold-rolled and annealed, percent					(c) Hot-rolled	(d) As rolled	(e) Annealed
	10	20	30	40	50	10	20	30	40	50			
Corrosion rate (mpy)	27.4	59.7	42.1	17.9	17.9	35.2	54.4	61.6	55.4	66.9	115.5	1.1	3.0
Exposure time			7.11 days					7.11 days			1.0 days	7.11 days	7.11 days
Spot-weld area:													
Description of attack			Cracking*					Pitting†			Cracking*	—	—
Area affected (percent)	20	78	62	0	10	33	36	57	53	68	32		
Sheared edges:													
Description of attack			Gullying					Pitting			Gullying	Cracking	Pitting
Edge affected (percent)	40	100	70	25	30	33	36	57	53	68	25	5	50
Affected area oxidized (percent)	100	100	100	100	100	54	55	92	50	50	100	0	0
Sample surface:													
Description of attack			Pitting					Pitted			Pitted	Stain	Pitted
Surface affected (percent)	0.4	13	14	9	3	33	36	57	53	68	6	5	50
Affected area oxidized (percent)	0	2	2	2	0	54	55	92	50	50	100	0	0

* Percentage of indented spot-weld periphery cracked.
† Percentage of spot-weld area pitted.

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for examination (note arrow in Figure 1A). This area was chosen to eliminate any stress influence from the sheared edges. The metal underlying the stained area after removing 0.002-inch from the surface, showed extensive intergranular attack (note upper field of photomicrograph Figure 9). The lower field in this figure underlies the adjacent unattacked surface area. A transverse section through a stained area of the sample in Figure 1B, exposed to RFNA in an earlier run for 30 days without mishap, showed the intergranular attack to penetrate halfway through the 0.041-inch sample thickness (note Figure 10). Although the weight loss here was moderate (6.32 mpy), the metal was easily broken with the fingers and exhibited a dull ring when struck. Staining, as illustrated, was thus found to indicate subsurface integranular attack and its occurrence was limited to the stock from manufacturer B.

To determine the nature and depth of pitting attack, a transverse section was made through an unignited pit, similar to X in Figure 2. The pit is seen in transverse section in Figure 11 to be intergranularly corroded, the depth of corrosion being quite shallow (approximately 0.0006-inch depth). Ignition of pitted areas was extensive in the annealed series b) samples and, judging from the areas affected, contributed significantly to the force of the blast.

Stress-corrosion cracking in unannealed spot welds was found to be largely confined to the outer periphery of the electrode indentation (note Figure 4). The cracking, for the most part, penetrated the thickness of the strip along a path outside the weld nugget and heat-affected zone. These features are seen in Figure 12, a transverse section through the center of series a) spot weld. It would thus appear that stress-corrosion cracking in spot welds is a function of surface stresses set up at the electrode periphery.

Although comparatively few samples in the explosion run had rolled edges (that is, they had edges of the original as-rolled sheet), it is noteworthy that attack from this stress source (see Figures 5 and 6) was quite extensive. Photomicrographs (Figures 13 and 14) made in this area after the surface was ground show the attack to be intergranular.

Sheared-edge samples of series a) and c), showing edge attack similar to that seen in Figures 7A and 7B, were sectioned transversely to determine the depth and nature of this type of attack. Figures 15A and 15B are photomicrographs of series a) and c) material, respectively, showing in section the depth of gullying at sheared edges and the hard, light etching oxidized spatter. The dark etching areas, indicated by the arrows, show that during the explosion the metal here was heated above the transformation temperature (885 C). The heat emitted from oxidation of the corroded material therefore must have been considerable. In Figure 8 spatter from the sheared edge of an overlying sample is seen to outline the region of overlap. Figure 16 is a section through a similarly spattered area. It is observed that the heat emitted by the spatter material was sufficient to anneal the underlying worked metal to a depth of 0.002-

(Continued on Page 98)

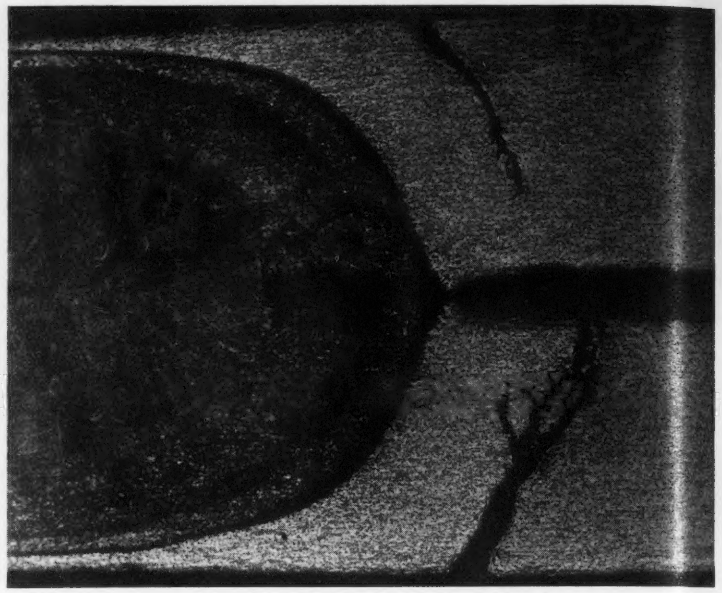

Figure 12—Transverse section through a series a) spot weld. Spot-weld perimeter cracking is seen to be removed from heat-affected zone. Keller's etch. 35X.

Figure 13—Micrograph of cracking at rolled edges shown in Figure 5. Field shown is parallel to the surface. Keller's etch. 64X.

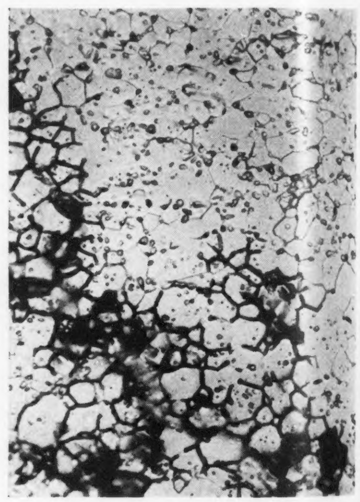

Figure 14—Same area as Figure 13; cracking is seen to be intergranular. Keller's etch. 337X.

TABLE 2—Analysis of Sheets

SOURCE	IMPURITY (Percent) Fe	C	N	Mg	Mn
Manufacturer:					
Sheet 1	0.14	0.056	0.028	0.005	0.079
Sheet 2 (series d & e)	.14	.064	.028	.005	.081
Sheet 3	.15	.044	.028	.005	.082
Manufacturer A—lot 1	.21	.043	.018	.005	.01
Manufacturer A—lot 2					
Hot-rolled (series c)	.39	.221	.019	.005	.024
10 percent cold-rolled*	.40	.196	.017	.005	.023
20 percent cold-rolled*	.39	.200	.016	.005	.024
30 percent cold-rolled*	.42	.206	.017	.005	.022
40 percent cold-rolled*	.41	.203	.017	.005	.022
50 percent cold-rolled*	.30	.179	.018	.005	.022

* Series a and b.

Report on Investigation—

(Continued From Page 96)

inch. The sheared edges of series d) samples underwent severe intergranular attack without any ignition of the corroded material. Figure 17 shows a sectional view through a sheared edge of a sample in this series.

Since the stress-corrosion attack at unannealed sheared edges figured so prominently in the explosion, it is of interest to illustrate in profile the texture and severity of deformation of an unsupported and supported sheared edge (note Figures 18 and 19).

Analytical Determination of Impurities

Several lots of commercial-grade titanium sheet were used in preparing test samples for RFNA corrosion studies. The analysis of these sheets is presented in Table 2 for further reference.

It is noteworthy that in the earlier runs made by the corrosion laboratory with RFNA, sheets 1, 2 and 3 from manufacturer B and lot 1 from manufacturer A, were used without mishap, even though severe intergranular corrosion occurred. The sample edges were sheared and spot welds prepared in a manner similar to that employed in the explosion run. Series d) and e) samples of the explosion run were cut from stock from manufacturer B. These sample slikewise showed attack but no ignition. The sample series a), b) and c) cut from lot 2, manufacturer A, were therefore the only commercial-grade titanium to be rendered pyrophoric on exposure to RFNA.

It is observed from Table 2 that lot 2, manufacturer A, shows a significantly higher iron and carbon content than the other two.

Iron is soluble in alpha titanium to 0.1 percent; the balance is present in a metastable secondary phase of beta titanium. This iron-rich phase is seen in the micrograph of the series a) sample, Figure 14, as fine globules concentrated largely at grain boundaries. Intergranular attack observed in this figure resulted in removal of the globular phase to the extent that a lower iron content would be anticipated in the attacked unignited surface areas of the series a), b) and c) (high iron content) samples. X-ray analyses were made of the surface layers of pitted unignited samples in the a) b) and e) series with the results shown in Table 3.

Iron Content

Since X-ray spectroscopy averages the iron content in the top thousandths of an inch or so in a one-half inch square of surface area, it is apparent here in the a) and b) series samples that the iron content in the surface layers is reduced in proportion to the area attacked. Confirmatory data were obtained here on other samples. It follows that the intergranular corrosion accompanying pitting attacked the iron-rich phase concentrated at the grain boundaries in the a) and b) series samples and reduced the surface iron content. Likewise, since the iron content in the series e) samples was largely in solution, it was not significantly reduced by intergranular attack.

Although high iron content in the a), b) and c) samples may conceivably have accelerated corrosion by providing avenues of attack in the form of an iron-rich grain boundary phase, it is presumptuous to state with the evidence at hand that high iron content necessarily rendered the corrosion products pyrophoric.

Carbon Content

The carbon content of the corrosion products of the series b) samples was determined colorimetrically from surface scrapings of attacked unignited areas to be twice or perhaps three times that of the base-metal content of 0.20 percent carbon. A carbon combustion analysis was made from millings cut from the

(Continued on Page 100)

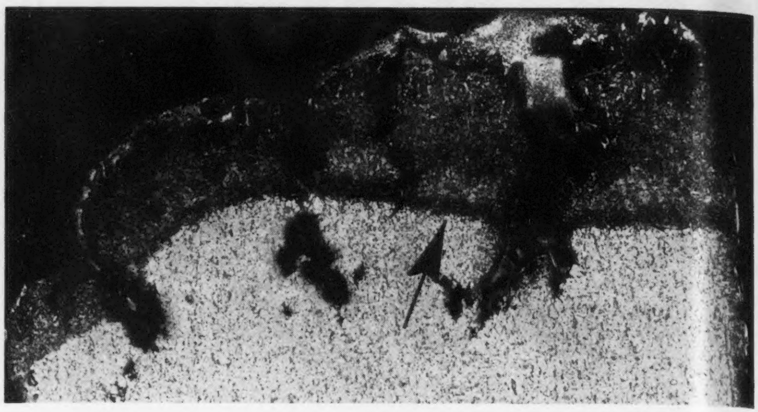

Figure 15A—Micrograph of section through sheared edge of series a) sample. 111X.

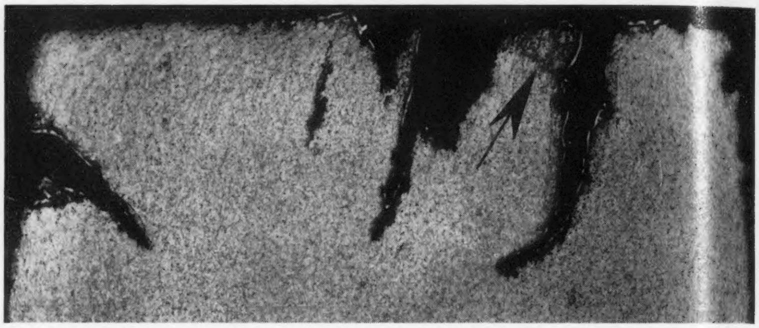

Figure 15B—Micrograph of section through sheared edge of series c) sample. Arrow indicates dark etching area where the metal exceeded the transformation temperature (885 C). Keller's etch. 111X.

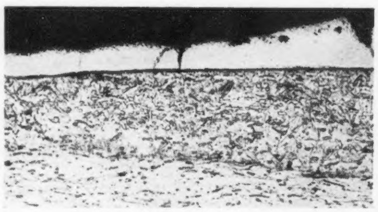

Figure 16—Section through spattered surface area similar to that seen in Figure 8. Top light etching area is spatter material. Heat affected zone varies with the thickness of the spatter. Keller's etch. 268X.

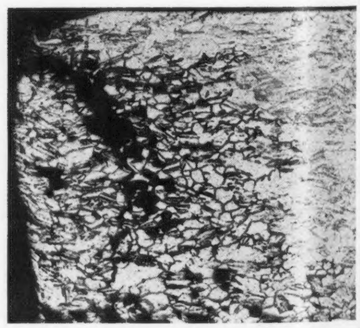

Figure 17—Sectional view through sheared edge of a series d) cold-rolled sample. Ignition of intergranularly corroded material is not observed. Keller's etch. 50X.

TABLE 3—X-Ray Analyses of Surface Layers

Sample	Surface Condition	Fe
Series (a), No. 20H	13 percent of surface pitted	0.32
	Base metal*	.37
Series (b), No. 50T	90 percent of surface pitted	.17
	Base metal*	.39
Series (e), No. Y	90 percent of surface pitted	.10
	Base metal*	.11

* Corrosion products were ground from the opposite sample surface and the base metal analyzed for Fe by X-ray spectroscopy.

Report on Investigation–

(Continued From Page 98)

ignited sheared edges of several series a) samples, (note figures 15A and 15B) to a depth of 0.015-inch. Unfortunately, a large portion of base metal was included in the millings along with the corrosion products. Nevertheless, a carbon increase was obtained here also; 0.245 percent carbon, as compared with a base-metal content of 0.196 percent carbon.

A carbon combustion analysis was also made on the intergranular corrosion products of an earlier run on manufacturer B's material exposed to RFNA in which corrosion products did not ignite. Figure 10 is a macrograph of a transverse section of a sample from this earlier run. Cuttings 1 mm thick from the sheared edges of these samples analyzed 0.152 percent carbon, as compared to a base metal value of 0.044 percent. It is thus concluded that the carbon impurity was attacked less than the titanium in the intergranularly corroded areas. Although the carbon was not depleted in the corrosion products as was the iron, there is no reason to exclude the function of the carbon as a possible catalyst in promoting the explosion.

Nitrogen Content

Nitrogen, the third impurity analyzed in the explosion products, showed no significant change over the base-metal value. This element also was analyzed from sheared-edge cuttings taken from samples of the early RFNA run, illustrated in Figure 10. The intergranularly corroded cuttings analyzed 0.031 percent nitrogen, as compared with the base-metal content of 0.028 percent, the difference here being small.

Discussion

A staining type of surface attack, observed in the cold-rolled samples, series d) was found to indicate extensive subsurface intergranular attack resulting in general embrittlement. Staining accompanied by intergranular corrosion was also observed in earlier RFNA tests on the same heat of titanium metal; no ignition of disintegrated material has been noted to date in this type of attack. Contrary to this, the cold-rolled samples, series a), showed a pitting type of attack. Pitting in these samples did not exceed 14 percent of the surface area; maximum attack occurred between 20 and 30 percent cold roll. To the extent of the run there is an indication that a critical deformation exists in the 20 to 30 percent cold-rolling range to favor maximum pitting attack. Ignition of the pitted areas of the cold-rolled samples was light and did not involve more than 2 percent of the surface pits.

Both the annealed series, b) and e), samples showed an equal degree of surface pitting, that is, covering approximately 50 percent of the surface area; neither series showed stress-corrosion attack, thus indicating complete stress relief. Although more than 50 percent of the pitted area in the series b) samples ignited during the explosion, showing a high degree of oxidation, none of the series e) samples ignited.

It is considered that the dissimilarities noted above in the nature of the surface attack in the cold-rolled material from manufacturers A and B and the failure of any of the corroded material in the samples from manufacturer B to ignite during the explosion may be attributed in part to chemical differences in the two materials. The carbon and iron content of lot 2, manufacturer A (0.40 percent iron, 0.20 percent carbon), ran about three times that of lot from manufacturer B (0.14 percent iron, 0.064 percent carbon).

It may be noted here that the ASTM Tentative Specification B265-52T for unalloyed titanium sheet limits the iron content to 0.25 percent maximum. Analytical results show that in the unignited corroded material the percentage carbon increased, the percentage nitrogen remained essentially unchanged and the percentage iron was depleted; however, the procedure and outcome of the test in question did not permit definitely establishing the fact that either iron or carbon contributed to a sensitive pyrophoric condition.

Corrosion Followed Stress Direction

Stress-corrosion attack observed in the test samples under question followed the direction of stress. In spot welds, the stress-corrosion cracking followed the periphery of the indentation and generally extended through the thickness of the sheet. A few of the samples had rolled edges. Rolling sets up transverse fissures at the rolled edge, which act as stress raisers. Transverse corrosion cracking from this stress source was observed to propagate as far as 0.1-inch in from the sample edge. Shearing stresses are largely longitudinal, depending, however, in degree and direction on the shear pattern.

Attack at sheared edges extended to a depth of 0.01-inch. Sheared-edge stress-corrosion attack was almost as extensive in the warm-rolled sample, c) series with only one day exposure, as it was for the cold-rolled series a) samples with 7.11 days exposure before the explosion. The fact that attack on the hot-rolled specimens was almost exclusively at the sheared edges and that the rate of attack was very high may be the result of electrochemical effects between the active metal at the sheared edges and the relatively inert oxidized surfaces.

The attack on the cold-rolled specimens was concentrated at the edges to a small degree. This may have occurred because the oxide coating on the surfaces of these specimens was thinner and hence the difference of potential between the surfaces and the edges was smaller. Corrosion of vacuum-annealed specimens was more uniform because these differences may have been eliminated by stress relieving at 800 C. It has also been suggested that the attack on the edges of hot-rolled specimens appears to be unusually heavy because most of the corrosion at sheared edges normally takes place during the first day of immersion. However, there is no evidence for the theory that corrosion at the edges stops after one day.

Spatter was observed in all of the stress-corrosion areas of the material from manufacturer A. Spatter in the crevices of spot-weld cracking was infrequent, so that the heat liberated from this ignition would be minor. Attack at the rolled edges showed a moderate degree of spatter. However, since only a few of the samples had rolled edges, the heat evolved from oxidation of disintegrated material here did not contribute significantly to the total heat of the explosion. Spatter from the unannealed sheared edges of the material from manufacturer A was general and extensive.

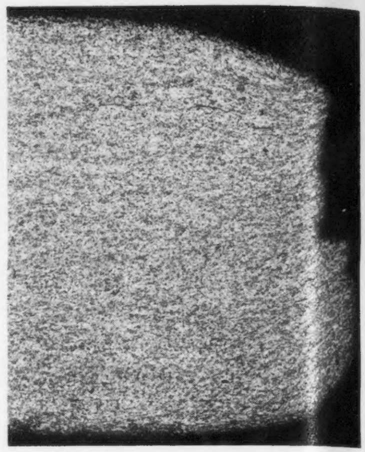

Figure 18—Profile of unsupported sheared edge, illustrating severity of deformation. Keller's etch. 66X.

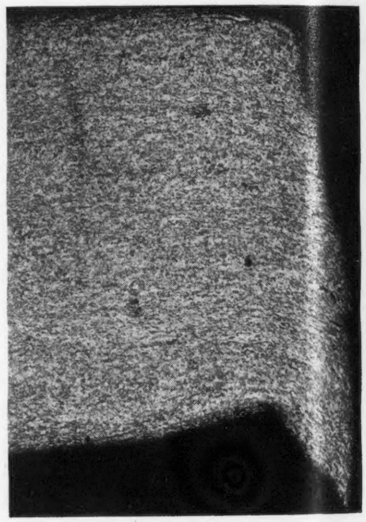

Figure 19—Profile of supported sheared edge, illustrating severity of deformation. Keller's etch. 69X.

Friction Triggers Blast

It appears that the explosion was triggered by friction between samples created during venting one of the flasks. During the course of the explosion, a sudden rapid oxidation of the products of corrosion took place in some selected areas, with evolution of large amounts of heat. Where the heat was intense enough the products of oxidation fused and were expelled.

Although the oxidized pitted areas occupied considerable surface, they were too shallow to generate enough heat during oxidation to cause fusion. In the sheared edges, however, where stress had not been relieved by annealing, corrosion was deep and the oxidation of disintegrated material generated enough heat to cause melting and spatter. Because of the evident loss of molten material at sheared edges, it is felt that these areas had more effect in causing

(Continued on Page 102)

South Central Region's New Officers Nominated

The following have been nominated for election to offices of the South Central Region, each for terms for one year, to take office on January 1, 1956, except for the director whose term will be for three years and who will take office March 16, 1956. Ballots will be sent to the members of the South Central Region.

For Director—For a three-year term beginning March 16, 1956, Harry E. Waldrip, Gulf Oil Corporation.

For Chairman—For a one-year term beginning January 1, 1956, John W. Nee, Briner Paint Manufacturing Company, Inc.

For Vice-Chairman—For a one-year term beginning January 1, 1956, Jack P. Barrett, Stanolind Oil & Gas Company.

For Secretary-Treasurer—For a one-year term beginning January 1, 1956, J. C. Spalding, Jr., Sun Oil Company.

For Assistant Secretary-Treasurer—For a one-year term beginning with January 1, 1956, J. A. Caldwell, Humble Oil & Refining Company.

Elkins Moderates Panel At Permian Basin Session

At the June 13 meeting of Permian Basin Section at the Lincoln Hotel in Odessa, Texas, approximately 65 members and guests heard a panel moderated by R. L. Elkins, Shell Oil Company, Midland, discuss casing corrosion. Prior to opening the meeting for a general discussion, the members of the panel presented discussions on the following subjects: J. D. Sudbury, Continental Oil Company, "Cathodic Protection;" J. A. Caldwell, Humble Oil & Refining Company "Use of Inhibitors;" H. E. Greenwell, Atlantic Refining Company "Use of Ammonia;" J. L. Ward, Shell Oil Company "Casing Corrosion Survey of The Permian Basin."

The next regular meeting of the section is scheduled to be held July 11 at the Lincoln Hotel.

Several Papers Committed For New York Meeting

Committments for technical papers to be delivered during the Chemical Industry Symposium at the NACE 12th Annual Conference and Exhibition at New York, March 12-16 have been received as follows by J. J. Heger, symposium chairman:

Reducing Maintenance Painting Costs in the Chemical Industry, M. L. Monack, E. I. duPont de Nemours & Co., Ltd.; Corrosion of Metals by Liquid Fertilizer Solutions, by D. C. Vreeland and S. H. Kalin, United States Steel Corp., Pittsburgh, Pa. Hugh P. Godard, Aluminium Laboratories, Ltd., Kingston, Ont. will present a paper the title of which is not yet known.

•

For the seven years 1945-51 inclusive covered in the NACE Bibliographic Surveys of Corrosion there are 12,414 abstracts of technical literature on Corrosion. Most of these include a complete reference to original publication.

New Correspondent for Ferrous Metals Named

G. M. Riegel, Republic Steel Corp., Metallurgical Laboratory, Massillon, Ohio has been named correspondent on ferrous metals on the Corrosion editorial staff. Mr. Riegel, who has been working on corrosion problems for nearly 20 years, is in charge of Republic Steel's Stainless Steel and Corrosion Department in its metallurgical laboratory. He is a graduate of the University of Wisconsin and University of Illinois.

Metal Show Scheduled at Philadelphia Oct. 17-21

The 37th Annual National Metal Congress and Exposition will be held October 17-21 at Philadelphia in the Convention Halls near the campus of the University of Pennsylvania. American Society for Metals is sponsoring organization and cooperating are Institute of Metals Div., American Welding Society, American Institute of Mining and Metallurgical Engineers and Society for Non-Destructive Testing.

Technical programs of the four cooperating societies will be held at their respective headquarters hotels.

Exhibit Invitations Are Sent Out for NACE Show

Invitations to exhibit at the 12th Annual Conference and Exhibition of the National Association of Corrosion Engineers have been sent out by Clark A. Bailey, chairman of the 1956 Exhibits Committee. The exhibition will be held at Hotel Statler, New York City, March 12-16.

Report on Investigation—

(Continued From Page 100)

the explosion than did the pitted flat surfaces.

Acknowledgments

The authors wish to acknowledge the courtesies extended and the assistance given by Dr. W. J. Huff, chief, Department of Chemical Engineering, University of Maryland, and Dr. C. E. White, professor of inorganic chemistry, University of Maryland.

The following employees of the College Park Station contributed to this report by supplying information on the accident and assisted in the rescue operation: L. B. Golden, chief, Chemical Corrosion Section; T. E. Green, chemist; Robert Warfield, chemist; L. A. DeVivo, laboratory mechanic; D. W. Chalkley, laboratory mechanic; E. H. Neagle, laboratory welder; and R. L. Heath, laboratory general mechanic.

Six Short Courses Yearly Reported by Hackerman

By NORMAN HACKERMAN
Chairman, Committee on Education

1. It was agreed to approve a request by the University of Illinois that NACE co-sponsor a short course in cathodic protection at Urbana in December, 1955. Ray Wainwright of the electrical engineering staff at the University of Illinois is actively concerned with giving the course and is our contact.

2. There appear to be about four general (1 Midwest, 1 South Central, 1 East + Canada, 1 West + Canada) and two specialized short courses given per year now. The need for a general short course format which can be sent to institutions and groups wishing to give such courses was apparent to all members of the committee.

It was agreed that a reasonable format should be based on ¼ to ⅓ of the total time devoted to basic chemistry and metallurgy of corrosion systems, and ¾ to ⅓ of the time devoted to preventive methods. The latter could be broken down into: separation of the reacting phases, reduction in reactivity of the environment, reduction in reactivity of the metal. There is some overlapping, but it is not serious. Furthermore, the number of lecturers at any one course should be kept to a minimum. For instance, in a course consisting of nine, 3-hour sessions, not more than nine lecturers are required. Another attempt will be made to write up a short syllabus for the committee's approval.

3. A procedure for the "Junior" Award was discussed and agreed upon. This was written up in single copy and turned over to the board of directors for approval. Its disposition is not yet known.

1954 Report of Regional Management Committee

By L. A. BALDWIN
Chairman, Regional Management Committee

I am glad to be able to advise that the number of new sections continues to increase. In 1953 we had 30 sections. At the 1954 meeting we reported the formation of 10 new sections bringing the total to 40 and at this meeting we have 48 sections and two more in the process of formation. One of these is in the Canadian Region, located at Edmonton.

Mr. Campbell, our secretary, has advised me that the following ten sections are now fully accredited with memberships of over 100: Baltimore, Chicago, Cleveland, Houston, Los Angeles, Metropolitan New York, North Texas, Philadelphia, Pittsburg and San Francisco.

We are holding a meeting of the Regional Management Committee this afternoon in Room 17. All Regional and Sectional officers are cordially invited to attend as this is an opportunity to discuss, in an unofficial manner, problems in the regions and sections. At the meeting this afternoon we plan to make an announcement of the new certificates adopted by your board of directors for presentation to retired chairmen of regions and sections. Also a certificate of membership for any member who desires one.

At last year's meeting Mr. Schmidt, chairman of the Technical Practices Committee, urged the cooperation of regional and sectional members in facilitating meeting of the T. P. Committee. This met with considerable success and Mr. Schmidt will be at our meeting this year to discuss the subject further.

Any other matters which are disturbing regions and sections should be brought up at the meeting.

Corrosion Abstracts

Index to CORROSION ABSTRACTS

Vol. 11 August, 1955 No. 8

1. GENERAL

1.2 Importance

1.2.2, 8.9.1, 3.5.8

The Level of Safety Achieved by Periodic Inspection for Fatigue Cracks. R. R. Shaw. *J. Roy. Aeronaut. Soc.*, **58**, No. 526, 720-723 (1954) October.

Discusses the risk entailed in the practice adopted by some authorities of permitting aircraft, of a design known to be prone to fatigue failure, to be used in service until fatigue cracks develop at the weak spot and are revealed by periodic inspection (usually by a dye-penetrant method).—BNF. 8698

1.4 Bibliographies and Indexes

1.4

1948-1949 Bibliographic Survey of Corrosion. Ivy M. Parker, Compiler. Hard cloth, 346 pp., 1954. Available from National Association of Corrosion Engineers, 1061 M & M Building, Houston 2, Texas.

Summaries of 3512 corrosion and corrosion prevention articles, books and brochures published in 1948-1949 are compiled in this volume. Abstracts by 30 technical societies were canvassed regularly for material taken from more than 500 sources the world over.

The NACE Abstract Filing Index is used to classify the material topically. Literature is put into eight main groups in the NACE system: general, testing, characteristic corrosion phenomena, corrosive environment, preventive measures, materials of construction, equipment and industries. Each main group subdivided. Topical cross-references are appended to each section.

The subject index, in addition to terms in the NACE Abstract Filing System, lists many metals and alloys by trade name and indexes them as to specific properties and to behavior in specific media. There are more than 2700 names in the author index; companies and associations are not listed. Referencing is to the classification and serial numbers of each abstract. These numbers and the reference data are emphasized by type style and arrangement. The appendix aids the user in locating and obtaining copies of unfamiliar foreign or domestic journals.

This is the third in a series of NACE bibliographies on corrosion literature. The preceding two volumes, covering 1945 and 1946-1947 respectively, contained 4448 abstracts. 8616

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CODE OF AGENCIES SUPPLYING CORROSION ABSTRACTS

Neither NACE nor the sources listed below furnish reprint copies.

ALL—The Abstract Bulletin, Aluminium Laboratories, Ltd. P. O. Box 84, Kingston, Ontario.

ATS—Associated Technical Services Abstracts, Associated Technical Services, P. O. Box 271, East Orange, N. J.

AWWA—Journal, American Water Works Association, Amer. Water Works Asoc., 521 Fifth Ave., New York 17, N. Y.

BL—Current Technical Literature, Bell Telephone Laboratories, Inc., Murray Hill, N. J.

BTR—Battelle Technical Review, Battelle Memorial Institute, 505 King Ave., Columbus 1, Ohio.

BNF—Bulletin; British Non-Ferrous Metals Research Association. 81-91 Euston St., London NW 1, England.

CBEC—Centre Belge d'Etude de la Corrosion (CEBELCOR), 17 re des Drapiers, Brussels, Belgium.

CE—Chemical Engineering, McGraw Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

EL—Electroplating. 83/85 Udney Park Road, Teddington, Middlesex, England.

EW—Electrical World, McGraw-Hill Publishing Co. 330 W. 42nd St., New York 18, N. Y.

GPC—General Petroleum Corp. of California. 2525 East 37th St., Los Angeles 11, Calif.

IIM—Transactions, The Indian Institute of Metals, 23-B, Notaji Subhas Road, P. O. Box 737, Calcutta, India.

INCO—The International Nickel Co., Inc. 67 Wall Street, New York 5, New York.

IP—Institute of Petroleum. 26 Portland Place, London W#1, England.

JSPS—Japan Society for the Promotion of Science, Address: Mr. Hayata Shigeno, Secretary, Committee of Preventing Corrosion, c/o Government Chemical Industrial Research Institute, 1-Chrome Nakameguro, Meguro-ku, Tokyo, Japan.

MA—Metallurgical Abstracts, Institute of Metals, London, England. 4 Grosvenor Gardens, London SW 1, England.

MI—Metallurgia Italiana, Associazone Italiana di Metallurgia. Via S. Paola, 10, Milano, Italia.

MR—Metals Review, American Society of Metals. 7301 Euclid Ave., Cleveland 3, Ohio.

NALCO—National Aluminate Corp. 6216 West 66th Place, Chicago 38, Illinois.

NBS—National Bureau of Standards. Supt. of Documents, U. S. Gov't Printing Office, Washington 25, D. C.

NSA—Nuclear Science Abstracts. United States Atomic Energy Commission, Technical Information Division, Oak Ridge, Tenn.

PDA—Prevention Deterioration Abstracts. National Research Council, 2101 Constitution Ave., Washington 25, D. C.

RM—Revue de Metallurgie, Paris, France. 5 Cite Pigalle, Paris (9e), France.

RPI—Review of Current Literature Relating to the Paint, Colour, Varnish and Allied Industries, Research Association of British Paint, Colour & Varnish Manufacturers, London. Waldegrave Rd., Teddington, Middlesex.

SE—Stahl Und Eisen, Verlag Stahleisen, M. B. H., Dusseldorf, August-Thysen Str. 1. Postscheck Koln 4110, (22a) Dusseldorf, Germany.

TIME—Transactions of Institute of Marine Engineers. 85 The Minories, London EC 3, England.

UOP—Universal Oil Products. 310 South Michigan Ave., Chicago, Illinois.

ZDA—Zinc Development Association. 34 Berkeley Square, London W.1.

1.5 Directories of Material

1.5, 6.1

16th Biennial Materials of Construction Report. *Chem. Eng.*, **61**, No. 11, 171-234 (1954) November.

Survey sums up the corrosion resistance, properties, forms and uses of the most common materials of construction including iron, steel, cast iron, special cast irons such as nodular, Duriron and Durichlor, stainless steels, Chlorimet-Hastelloy alloys, Worthite, aluminum, copper and alloys, lead, nickel and alloys, such as Monel and Inconel, tantalum, plastics, carbon and graphite, rubbers, cements and resins. Corrosion data charts covering 36 materials vs. 48 corrosives are included as well as a directory of materials giving manufacturers, composition and applications.—INCO. 8574

1.6

Text-Book of Metallurgy. A. R. Bailey. 1954, 560 pp. Macmillan and Co., Ltd. St. Martin's Street, London.

Mr. Bailey is to be commended for attempting, with considerable success, to provide in a book of 560 pages a comprehensive introduction to general metallurgy for students at universities and technical colleges, to whom the reviewer particularly recommends the book. The author first deals with the nature, structure and properties of metals and alloys and the methods used for the examination of metallic structures, and considers the extraction and refining of metals both ferrous and non-ferrous. The melting, casting, working and testing of metals are then discussed and a final chapter covers temperature measurement. Space has been found for useful introductions to atomic theory, X-ray diffraction and the physical chemistry of thermal oxidation and reduction processes. A few errors have inevitably crept in: thus Fig. 20 is upside down; and on page 20 it is incorrectly stated that with plastic metals compression can be continued under constant true stress if friction is eliminated. A certain amount of generalization and oversimplification is unavoidable in a book of this kind, which makes the guide to further reading at the end of each chapter particularly useful. Collected examination questions are appended.—BNF. 8404

1.6 Books

1.6, 6.1, 3.1

Deterioration of Materials. Causes and Preventive Techniques. Glenn A. Greathouse and Carl J. Wessel, editors. Book, 1954, 835 pp. Reinhold Publishing Corp., New York.

Atmospheric, chemical, and biological deterioration of metals, wood, paper, textiles, plastics, rubber, coatings, and electronic, optical, and photographic equipment. —BTR. 8538

1.6, 6.2.1, 3.7.2

Nickel in Iron and Steel. A. M. Hall. Book, 595 pp., 1954. John Wiley & Sons, Inc.

Reviews and correlates important published data on nickel as an alloying element in steel and cast iron. Corrosion and the welding of nickel steels, structure and heat treatment of wrought and cast nickel steels, and the mechanical properties of cast irons containing nickel are a few of the important subjects discussed. —INCO. 8553

1.7 Organized Studies of Corrosion

1.7.1

Research and Information Services Available in the Fight Against Corrosion. (In Italian). M. Pourbaix. *Metallurg italiana*, **46**, special supplement to No. 5, 136-140; disc. 140 (1954) May.

Research work and organization of Belgian Center of Corrosion Study. 13 references.—BTR. 8680

1.7.1

Organization and Activity of Research and Testing in the Field of Corrosion at the Breda Istituto di Ricerche Scientifiche Applicate all'Industria. (In Italian). L. Matteoli. *Metallurgia italiana*, **46**, special supplement to No. 5, 147-148 (1954) May.

Outline of current activity. 31 references.—BTR. 8590

2. TESTING

2.3 Laboratory Methods and Tests

2.3.2, 2.2.2

Humidity Cabinets Don't Tell the Whole Story. L. Schlossberg. Quaker Chemical Products Corp. *Steel*, **135**, No. 2, 114-116, 118 (1954) July 12.

Field evaluation results are compared with accelerated laboratory test results in the investigation of corrosion preventives. Photographs show poor correlation between humidity tests and industrial conditions; steel panels exposed for 6 months at an industrial location are compared with panels in humidity chamber for 20 days at 100°F. and at 100% relative humidity. Development of accelerated testing is outlined. 15 references.—INCO. 8641

2.3.2, 5.8.2, 8.4.3

Laboratory Evaluation of Inhibitors for Sweet Gas-Condensate Wells. P. J. Raifsnider, R. S. Treseder and A. Wachter. *Corrosion*, **11**, No. 1, 19-21 (1955) Jan.

Simple test methods are described for laboratory evaluation of corrosion inhibitors for use in sweet gas-condensate wells. A rotated bottle type test at 180°F. with a steel strip in a mixture of kerosene and water is used to screen possible inhibitors. Additional tests under varied conditions are made to evaluate persistence of inhibition. A sealed tube test has been developed to assess the corrosiveness of concentrated inhibitors to steel at well bottom temperatures.

Good correlation has been obtained between the laboratory screening test results and field trial experience. 8460

2.3.4

Determination of Oxygen in Certain Gases. L. Silverman and W. Bradshaw. North American Aviation, Inc., Contract AT-11-GEN-8, April 15, 1954, 35 pp.

Present day studies of corrosion of metals by liquids necessitate the preparation and analysis of inert gas blankets free, or nearly free, of oxygen. Micro amounts of oxygen may be determined in the inert gases, hydrogen, nitrogen and carbon dioxide by a modification of the Winkler method, in which the oxygen is absorbed in manganous hydroxide; an equivalent amount of iodine is liberated, then extracted into ortho-xylene and determined colorimetrically. The analysis takes place at low pressures, from 350 to 760 mm Hg, whereby a small volume of gas (250 to 500 milliliters) can be analyzed. A reproducibility of 0.7 parts per million or better was obtained over a range of 0 to 25 parts per million of oxygen (microliters per liter). The method can be extended to 150 parts per million of oxygen by extracting into larger quantities of ortho-xylene. Improved methods of removing dissolved oxygen from analytical reagents result in a constant, but low, blank which permits the degree of precision obtained. (auth).—NSA. 8653

2.3.5

A New Method for Measuring Potentials of Polarized Electrodes in Soil Corrosion Cells. W. Neighbours. *Corrosion*, **11**, No. 2, 28-30 (1955) Feb.

A method of interrupting the current through a soil corrosion cell and of measuring the potentials of the polarized electrodes during the period of interruption is described. An electronic circuit is used to interrupt the current and the potential across the cell at interruption is balanced against a known potential, an oscilloscope being used as a null indicator. 8452

2.3.5

A Potentiostat for Corrosion Study. M. H. Roberts. Brown-Firth Research Labs., Sheffield, England. *Brit. J. Applied Physics*, **5**, 351-352 (1954) Oct.

The potential difference between a standard electrode and a test electrode in an electrolytic cell forms the input to a thermionic d-c amplifier. The output current of the amplifier flows between the test electrode and a third electrode of platinum. Any change in potential of the test electrode alters the output current to reduce the charge, the system forming a closed-loop proportional controller. The two-stage amplifier is symmetrical, so that zero or reverse current can be obtained without loss of sensitivity. An output of 20 ma can be supplied with less than 100 mv variation of electrode potential. (auth).—NSA. 8635

2.3.5, 2.2.6

Laboratory Measurement of Corrosion in Soils. *Tech. News Bull. Natl. Bur. Standards*, **38**, 13-14 (1954) January.

Six-month test is shown to agree with ten-year field tests. Cell uses differential aeration of metal discs in contact with soil.—BTR. 8594

2.3.5, 2.3.6

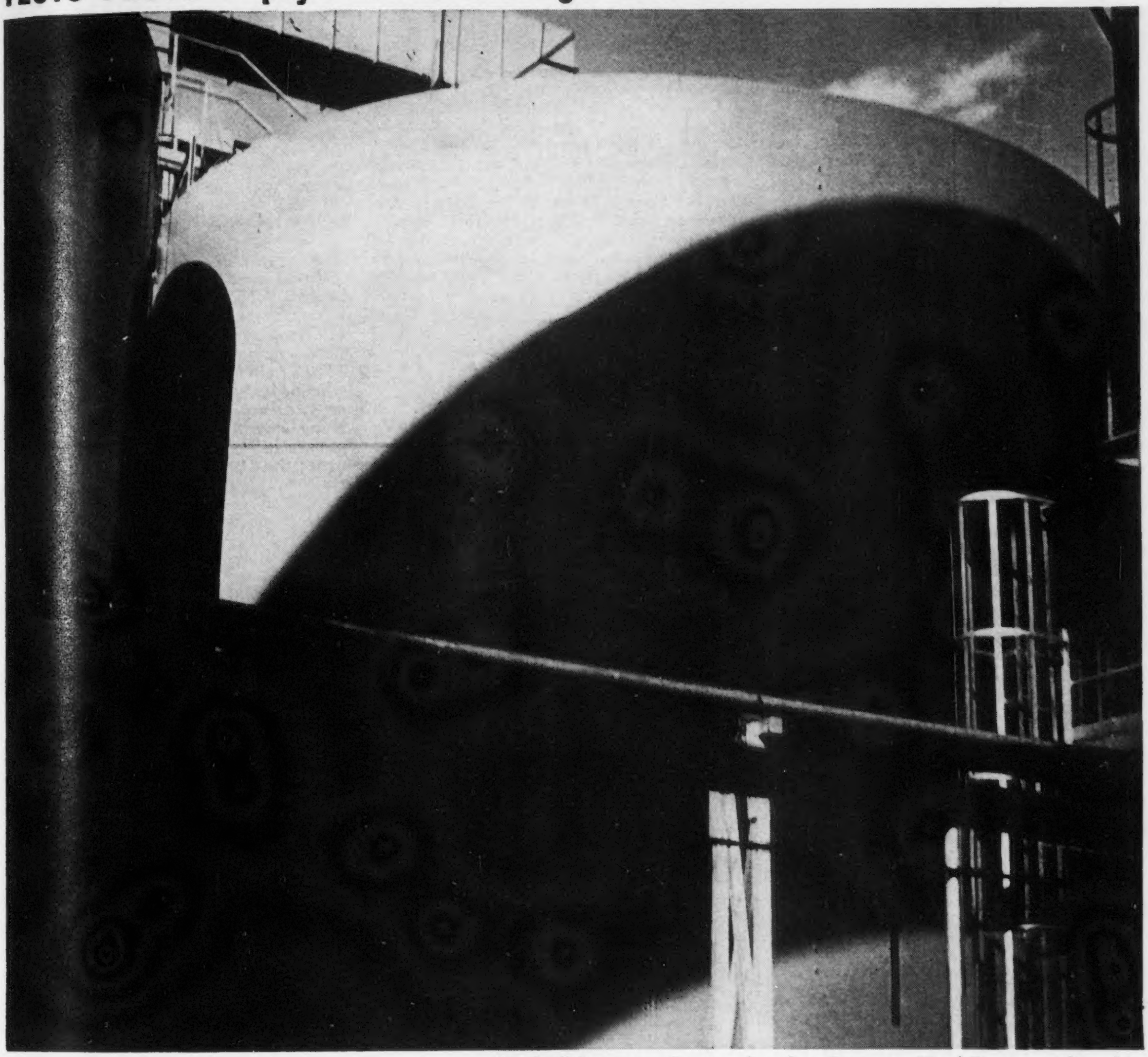
Exploration of Metal Surfaces with Fine Wires. R. H. Savage and D. G. Flom. General Elec. Co. *Annals of the New York Academy of Sciences* (Symp. on Properties of Surfaces), **58**, No. 6, 946-950 (1954) Sept. 15.

Discussion of a very sensitive method of exploring small regions (less than 10^{-4} cm.^{2}) on conducting surfaces with fine (diameter 2-mils or less) curved-wire probes. Platinum was used for the probes to avoid high resistance films in the measuring circuit, and gold was used alternatively.—INCO. 8686

2.3.5, 2.4.3, 7.2

Tentative Standard Method for Measuring Electrical Conductance of Coating On Buried Pipe Lines. A Report of Technical Unit Committee T-2D on Standardization of Procedures for Measuring Pipe Coating Conductance. William F. Huddleston, Chairman. *Corrosion*, 11, No. 2, 59-62 (1955) Feb.

A general method and an attenuation



method for measuring the electrical conductance of buried or submerged pipe lines are proposed. Definitions, test conditions and set up, instruments, procedures, calculations and methods of reporting results are covered. Appendix includes pertinent formulae, suggested forms for making reports. 8462

2.3.5, 6.2.5, 3.6.5

Method for the Study of Corrosion Phenomena. C. EDELEANU. *Nature,* **173,** 739 (1954) April 17.

The rate of corrosion of stainless steels was measured while the potential was held constant at various values by a potentiostat. Much useful information is obtained from the resulting curve of corrosion rate against potential; in particular, the wide range of conditions under which the oxide film is stable and the corrosion rate very low is defined.—BNF. 8556

2.3.5, 6.3.6, 3.5.8

On the Use of Electrical Resistivity As a Measure of Plastic Deformation in Copper. R. H. PRY AND R. W. HENNIG. *Acta Metallurgica,* **2,** No. 2, 318-321 (1954) March.

It has been shown that, for fine-grained polycrystalline copper, the stress necessary to continue plastic deformation in tension, below ordinary recovery temperatures, can be determined by measurements of the temperature, strain rate, and residual electrical resistivity measured after a room temperature anneal. Graphs and 7 references.—INCO. 8726

2.3.5, 6.3.20

Method of Estimating the Local Corrosion Current on Zirconium. (In Italian). M. MARAGHINI AND P. VAN RYSSELBERGHE. *Metallurgia italiana,* **46,** special supplement to No. 5, 45-46 (1954) May.

Method uses artificial separation of anodic and cathodic zones. Diagrams, 4 references.—BTR. 8660

2.3.6, 3.7.4, 3.6.5

The Mechanism of Metallographic Etching. I. The Reaction Potential of a Two-Phase Brass in Various Etching Reagents. G. L. KEHL AND M. METLAY. *J. Electrochem. Soc.,* **101,** No. 3, 124-127 (1954) March.

Specimens of the brass (60.75% copper, 38.55% zinc, remainder manganese, iron, silicon, lead), were coated with resin except for an isolated portion of the phase being investigated. The potentials of the phases in 9 etching reagents were measured; the potential of the beta phase was consistently 0.01-0.03V more anodic than that of the alpha in the same solution. Grain boundaries seemed to be anodic to the grains.—BNF. 8412

2.3.7

Local Tendencies to Change of "Solution Pressure" of Metals Under Low Stresses. (In German). P. KOCH. *Metalloberflache,* Sec. A, **8,** A1-A7; A37-A41 (1954) Jan., Mar.

Solution pressure is defined as the EMF produced by system (stressed metal immersed in liquid) due to ion migration (metal to liquid only). Variation in solution pressure is due to variations in stress: possibility of applying measurements of

this change to stress-corrosion problems. Purpose of investigation is attempt to prove relation between crystalline slip of stressed specimens and changes in solution pressure by measuring potentials on surfaces under different stresses and metallographic investigations. Low stresses only were investigated. Experimental set up and details for measurement of potentials of stressed, immersed specimens are given. Materials investigated were: Armco iron, copper, platinum, zinc, St. 52 and V2A steels. Potential/stress curves show breaks at certain stresses; repeated stressing of same specimen raises stress at which break occurs. Factors contributing to this effect are discussed. Control tests on stress behavior, using mirco tensile apparatus are described. Metallographic examination of specimens (data only for zinc) was made.—INCO. 8417

2.3.7, 2.4.2

A Fatigue Testing Machine for Range of Stress. J. P. Romualdi, C. L. Chang and C. F. Peck, Jr. *A.S.T.M. Bull.*, No. 200, 39-43 (1954) Sept.

Describes a testing machine capable of subjecting rotating-beam fatigue specimens to a full range of loading from pure tension to pure bending or any combination of the two.—BNF. 8628

2.3.7, 2.4.2

Fatigue Testing Fixtures. T. R. Breunich. *Product Eng.*, **25**, No. 6, 200-205 (1954) June.

Design of fixtures for holding specimens in various types of fatigue testing machines: bending, torsion, tension-compression, simulated service.—BNF. 8566

2.3.7, 3.5.8

Some Remarks on Stress Corrosion Testing. Hugh P. Godard and J. J. Harwood. *Corrosion*, **11**, No. 2, 53-58 (1955) February.

Some of the theories relating to the influence of stress in accelerating corrosion are reviewed briefly. A warning is given not to make assumptions on the resistance to stress corrosion of a material solely on the basis of a timed test because of the cumulative nature of the phenomenon. The merits and uses of several kinds of stress corrosion tests are explained and some of the factors to be considered in evaluating results enumerated. Influence of the environment, metal structure, specimen orientation, surface area and finish are considered. The several means of applying stress to specimens, the devices used to apply the stresses and some of the merits and demerits of various testing devices are considered. 33 references. 8456

2.3.7, 5.3.2

Methods for Studying the Thermal Resistances of Sprayed and Electrodeposited Metal Coatings. R. W. Powell and M. J. Hickman. *Brit. J. Applied Physics*, **5**, No. 9, 312-315 (1954) Sept.

Methods for rough and smooth surfaces; with the latter the thermal resistance of both the coating metal and its bond to the basis metal can be studied. The thermal conductivity of sprayed steel was found to be much less than that of normal bulk steel.—BNF. 8689

2.3.7, 5.3.3

Present Position of German Standardisation as a Basis for Investigation of Electrodeposits. (In German). G. Schikorr. *Metalloberflache, Series B*, **6**, No. 4, B57-B60 (1954) April.

In view of intensive German activities in electroplating and allied fields (30 specifications or drafts are listed by title), discusses relation of the specifications to testing of thickness (microscope, solution, nondestructive methods), porosity, corrosion, surface textures.—BNF. 8642

2.3.9

Continuous Polarographic Investigation of the Kinetics of Corrosion. (In Italian). L. Riccoboni, P. Papoff, and V. Genta. *Metallurgia italiana*, **46**, special supplement to No. 5, 129; disc., 144 (1954) May. Equipment and techniques.—BTR. 8710

2.3.9, 6.4.4

Zinc in Magnesium Alloys. E. C. Mills and S. E. Hermon. *Metal Ind.* (London), **85**, No. 2, 32 (1954) July 9.

With the recent introduction of magnesium alloys containing 1-5% zinc, the gravimetric procedure for zinc determinations has become both tedious and diffi-

cult. A polarographic method using the following reagents: hydrochloric acid 25% w/v, sodium hydroxide 40% w/v, gelatin solution 0.55% w/v, has been found very suitable for control purposes and reproducibility of results is not affected by small percentages of zirconium, thorium and rare earth metals present in the new magnesium alloys.—ZDA. 8663

2.3.9, 4.7

A Technique for Corrosion Testing in Liquid Lead. John V. Cathcart and William D. Manly. *Corrosion,* **10,** No. 12, 432-434 (1954) Dec.; Oak Ridge National Lab., ORNL-1737, Contract No. W-7405-eng-26, Aug. 19, 1954, 7 pp.

A new testing technique has been devised which was found to be satisfactory for comparing the dynamic corrosion characteristics of a series of metals in liquid lead. The tests were conducted in small quartz thermal convection loops. The necessary apparatus was simple, easy to construct and relatively inexpensive. In addition the method afforded a means of studying metals such as chromium and molybdenum which, because of difficulties in fabrication or lack of oxidation resistance, could not be tested by more conventional techniques. 8469

2.3.9, 4.7, 3.7.2

Solutions in Liquid Iron. Pt. 3. Diffusion of Cobalt and Carbon. D. W. Morgan and J. A. Kitchener. *Trans. Faraday Soc.,* **50,** Pt. 1, 51-60 (1954) Jan.

Technique was developed for determining the diffusion coefficients of solutes in liquid iron. Radio-tracers are used to obtain concentration-distance curves after diffusion has occurred along a narrow column of iron. The method was tested by a number of measurements with cobalt and carbon as the diffusing elements. Results can be accounted for by treating liquid iron-cobalt solutions as substitutional alloys and iron-carbon solutions as disordered austenite. No other determination of the diffusion coefficient of cobalt in liquid iron has been reported. Graphs, tables and 20 references.—INCO. 8415

2.4 Instrumentation

2.4.2, 5.3.4

Laboratory-Scale Simulation of the Electro-Tinplate Manufacturing Process. R. Mills and C. J. Thwaites. *Sheet Met. Inds.,* **31,** No. 329, 733-737 (1954) Sept.

In a laboratory tinning line the electrolyte in the cell is pumped at high speed between stationary electrodes. This is believed to simulate industrial conditions while being more flexible than an actual small-scale model. Flow-brightening is carried out by high-current resistance heating. Apparatus was used to study the effect of various factors on the quantity of electro-tinplate, and the reaction between tin and iron during flow-brightening.—BNF. 8589

2.4.3

Ultrasonic Transparency of Steel and Its Bearing on the Results Obtained with the Pulse-Reflection Technique. A. Michalski. *Stahl und Eisen,* **74,** No. 1, 26-33 (1954).

Need for uniform longitudinal and transverse transparency of steel to ultrasound when estimating the size of internal defects. Attenuation of ultrasound before and after forging. Factors capable of producing misleading reflectograms; factors due to testing procedure; and factors due to condition of work piece being tested. Study of ultrasonic transparency of large forgings as function of position of specimen in cross section and of heat treatment. Influence of ferrite in grain boundaries, coarse structure, and carbon segregation on test results. Transparency as function of frequency selected for testing. Conclusions to be drawn as to design of ultrasonic testing apparatus (including the use of transducer adaptors) and as to the best testing procedure. Abridged translation available: Henry Brutcher, P. O. Box 157, Altadena, Calif. 8581

2.4.3

Some Factors of Importance in Ultrasonic Testing. J. B. Morgan. *Non-Destructive Testing,* **12,** No. 3, 13-18 (1954) May-June.

Investigation of some factors affecting the interpretation of ultrasonic flaw echoes in 14S-F alloy (aluminum-4 copper-1 silicon-1 manganese-0.5 magnesium). At a short distance from the probe indication rises to a maximum, then decays almost exponentially with increasing distances; with small test pieces reinforcement by reflection from the sides causes other maximum points in the curve. Size of crystal, frequency and instrument performance were examined. Probe sensitivity variations may cause variation of 100% in height of indication.—BNF. 8591

2.4.3

Contribution to the Theory and Practice of Ultrasonic Testing of Materials. (In German). H. J. Seeman and W. Bentz. *Metall,* **8,** No. 1/2, 1-11 (1954) Jan.

Fundamental physical considerations; methods and apparatus; practical applications; technique and practical results (folds; head cracks in screws; nonmetallic inclusions; segregation).—BNF. 8650

2.4.3

Selection of Methods for Nondestructive Inspection. ASM Committee on Nondestructive Inspection. *Metal Progress,* **66,** No. 1-A, 159-163 (1954) July 15.

Definition of methods, evaluating soundness of steel welds, detecting cold shuts in cast bronze bushings, inspection of heat resisting metals, determining soundness of aircraft turbine disks, and sorting mixed lots of steel. Tables. 26 references. —MR. 8655

2.4.3, 2.3.9

Radiographic Characteristics of High Energy X-Rays. A. L. Pace. *Non-Destructive Testing,* **12,** 21-25 (1954) March-April.

Utilization of high-voltage X-radiation in radiographic inspection reveals many interesting characterstics not observed with lower voltage X-rays. Graphs, diagrams, radiographs, photographs.—MR. 8606

2.4.3, 3.2.2, 6.2.5

Analyses of Metallic Sound as a Measurement of Intercrystalline Corrosion in 18/8 Stainless Steel. (In Italian). O. Masi and A. Ferri. *Metallurgia italiana,* **46,** special supplement to No. 5, 125-127; disc., 128, 140 (1954) May.

Theory, techniques, and applications. Tables, photographs, graphs.—BTR. 8742

2.4.3, 3.7.3

X-Ray While Hot to Speed Pipe Welding Inspection. J. K. Bell. *Industry and Welding,* **27,** 58+ (1954) August.

Nondestructive examination by hot

radiography permits quality checks on-the-spot at any stage and at temperatures up to 1200° F. Photograph, diagram, table. —MR. 8504

2.4.3, 8.8.1
Detecting Corrosion in Chemical Plant. H. MANLEY. *Corrosion Technology,* **1,** No. 9, 333-335 (1954) November.

Describes an ultrasonic thickness gauge and its use in the chemical industry to check for corrosion and wear in pipes, boilers and storage tanks without interfering with production. Formation of scale or other deposits on the wall being measured does not affect the readings. Principle of the ultrasonic gauge is covered, and actual installations where the gauge is currently in successful use are outlined.—INCO. 8666

3. CHARACTERISTIC CORROSION PHENOMENA

3.2 Forms

3.2.2, 1.7.1
Metals with Whiskers. S. M. ARNOLD. *Bell Labs. Record,* **32,** No. 11, 417-420 (1954) November.

Discusses growth of whiskers on zinc-plated parts of channel filters. Neither high relative humidity, elevated temperatures, nor the presence of organic matter are necessary to develop characteristic surface condition, indicating that corrosion as normally encountered is not the cause of the trouble. X-ray diffraction camera showed that filaments removed from zinc-coated filter bracket consisted of single crystals of metallic zinc. Metals other than zinc, cadmium and tin develop whiskers and some 2000 specimens are under test at present. Lacquer coatings are easily penetrated by whiskers. Illustrations.—INCO. 8515

3.2.2, 2.1.1
Notes on a System for Rating Pitting Corrosion. RUSSELL W. HENKE. *Corrosion,* **11,** No. 1, 50-52 (1955) Jan.

A system is proposed for describing corrosion pits in a metal surface by a combination of agglutinated numbers and letters coded to a schedule rating the five principal characteristics of pitting corrosion. The system would facilitate transmission of pitting data by providing a 10-digit number covering their depth, equivalent diameter (including those of irregular shape), area (expressed as a percentage of total surface), nature of pit walls and time (reduced to a standard interval).

Pit depth is expressed as a percentage of material thickness rather than a finite dimension, walls would be rated vertical or gradual in comparison with a 45 degree angle and time would be in penetration per year. Area of pits as percentage of total area would be determined by placing over the pitted surface a transparent grid and comparing the area visually with a conventional standard delineating 10 stages of severity.

Suggestions and recommendations for improvement of the system and submission of specimens of pitted material are solicited by the author. 8455

3.2.2, 6.3.14
Accelerated Growth of Tin Whiskers. R. M. FISHER, L. S. DARKEN AND K. G. CARROLL. *Acta Metallurgica,* **2,** 368-369, 371-373 (1954) May.

The growth rate of tin "wiskers" can be accelerated up to 10,000 times the previously observed spontaneous rate by applying pressures up to 7500 psi. These whiskers exhibit three stages of growth: an induction period (sometimes extremely short), a period of constant growth and a third period in which an abrupt transition to a much slower growth rate occurs. The growth rate during the second period is directly proportional to the applied pressure. The spontaneous growth rate corresponds to a free-energy dissipation of about 0.1 joule per g atom of tin and the fastest accelerated rate to about 10^4 times this value. The tin whiskers grow from the base rather than from the tip.—PDA. 8573

3.2.2, 5.9.2, 6.2.3
Some Effects of Hydrogen on the Delayed Fracture of High-Tensile Steel. W. A. BELL AND A. H. SULLY. Fulmer Research Inst. *J. Iron Steel Inst.,* **178,** Pt. 1, 15-18 (1954) September.

Investigation was made of the delayed fracture of 0.9% carbon steel in the form of circlips into which hydrogen was introduced by electrolytic pickling. After storage and tempering treatments, which produced a more or less complete recovery of the normal mechanical properties, the tendency to fracture with short delay times was greater for samples that had been pickled. Effect of hydrogen on the delayed fracture characteristics increased with the hardness of the steel. Results are discussed on the basis of the Griffith crack theory of brittle fracture. Table and 11 references.—INCO. 8483

3.2.3, 3.5.9, 6.2.2
Hot Oxidation of Iron. V. MONTORO. *Metallurgia italiana,* **46,** 410-412 (1954).

The behavior of iron hot oxidation, re-

lated with the temperature is discussed, together with the composition and adherence or compactness of oxide film formed.

The diagram of quadratic oxidation speeds identifies two different kinds of behavior, through two directrices having a different slope, respectively below and over 500C.

Occurrence of points which deviate from the upper directrix around 530 and 860C is to relate with oxygen penetration through the film porosities and cracks. A return to the normal conditions at temperatures of 700 and 1000C is probably due to the achieved impermeability of the ferric oxide layer.

These phenomena do not allow for detection of further more important singularities which could be expected on account of some modifications of metal properties, particularly with regard to the iron recrystallization and to its change to the "gamma" status.—MI. 8613

3.2.3, 4.2.1

The Charge of the Photographically Active Particles Emitted by Metals During Atmospheric Corrosion. (In Russian). I. L. Roikh and A. I. Shcherbak. *J. Phys. Chem. USSR.* (Zhur. Fiz. Khim.), **28,** No. 5, 769-771 (1954); Cf. Roikh, *Doklady Akad. Nauk SSSR,* **70,** 253-256 (1950) Jan. 11.

Photographic plates were exposed for 3.5 days to the action of zinc plates undergoing atmospheric corrosion. In each test three plates were used: one was subjected to a constant positive electric potential, the second to the negative potential of the same absolute value and the third was a control plate. There was no difference between the optical α of the plates thus exposed, which led to the conclusion that the photographically active particles emitted by metals do not carry an electric charge. This fact does not exclude the possibility that metals undergoing corrosion may emit charged particles which are not photographically active.—MA. 8633

3.2.3, 4.2.1

The Composition of the Photographically Active Particles Emitted by Metals During Atmospheric Corrosion. (In Russian). I. L. Roikh. *Doklady Akad. Nauk SSSR,* 94, No. 6, 1117-1120 (1954).

Photographic plates were placed over 0.01% hydrogen peroxide solution (for 2 hr.), over zinc plates (for 10 days), over 0.1% Na_3AsO_3 solution (for 2 hr.) and over 0.1% mercuric chloride solution (for 2 hr.), before and after exposure for 1 min. to monochromatic light of wavelength varying from 406 to 620 mμ. The curves showing the variation of optical α with wave-length obtained with hydrogen peroxide solution and zinc plates almost coincided, leading to the conclusion that the photographically active particles emitted by metals are molecules of hydrogen peroxide [cf. *ibid.,* **90,** 603-606 (1953) June 1.]—MA. 8634

3.2.3, 6.3.17

The Anodic Oxidation of Uranium. (In English). O. Flint, J. J. Polling, and A. Charlesby. *Acta Metallurgica,* **2,** No. 5, 696-712 (1954) Sept.

Rates of oxidation and structures of films from 2 to 100 v. Similarities of anodic and thermal oxidation. Tables, graphs, electron diffraction patterns. 13 references.—BTR. 8528

3.3 Biological Effects

3.3.4, 1.3

Corrosion of Pipes by Bacteria. L. T. MINCHIN. *Gas Age,* **114,** 45-47, 101-102 (1954) October 7.

European survey of microbiological anaerobic corrosion with special reference to experience in Low Countries. Table, photographs. 7 references.—BTR. 8672

3.4 Chemical Effects

3.4.8, 4.2.3

The Detrimental Effects of Sulphur in Fuels. A. PARKER. Paper before Inst. of Fuels, London, October, 1954. *Corrosion Prevention & Control,* **1,** No. 9, 547-552 (1954) November.

Typical examples of the difficulties and detrimental effects due to sulfur in fuels are reviewed. Sulfur has an adverse effect in making of iron and steel, in glassmaking, in boilers and furnaces, domestic heating appliances and in internal combustion engines. Corrosion damage by atmospheric sulfur and removal of sulfur from flue gases are discussed. Of the various methods investigated, the one showing the greatest promise is that in which the gases are washed with a solution containing ammonia. Table.—INCO. 8610

3.4.8, 6.3.10

On the Influence of Chloride Ions on the Mechanics of Dissolution of Nickel Anodes in Sulphate Baths. W. MACHU AND A. RAGHEB. *Werkstoffe u. Korrosion,* **5,** No. 6, 217-222 (1954) June.

Anodic behavior of nickel in nickel sulfate solutions was investigated, as was the effect of ammonium and nickel chloride additions. Best method for preparing the electrode was an anodic preliminary treatment in N-hydrochloric acid at 0.3-0.4 amp./sq. cm. At higher anodic current potentials an anodic polishing took place, while at lower potentials, the nickel only commenced to corrode, with insufficient removal of the surface layers. Ammonium or nickel chloride addition increased the porosity of primary oxide layer present on the nickel, thereby improving the solubility of nickel anodes. Porosities of surface layers of different electrolytes are calculated from the Muller-Machu log i_o t_p curves and the influence of chloride ions quantitatively determined. In comparison with pure nickel sulfate, mixtures of nickel sulfate and nickel chloride behaved differently, as was also the case when the behavior of these mixtures was compared with that of pure nickel chloride, hydrochloric acid and sodium chloride respectively. Mixtures show a very high activating power and, after anodic treatment, permit the formation of very porous and unstable surface layers. Formation of oxide layers during anodic polishing was demonstrated.—INCO. 8423

3.5 Physical and Mechanical Effects

3.5.3

Control of Cavitation in Pressure-Reducing Installations. W. A. KUNIGK. *J. Am. Water Works Assoc.,* **46,** 955-959 (1954) Actober.

Experience with two specific pressure-reducing installations in a distribution system and a practical approach to the elimination of cavitation erosion. Photographs, diagrams, graph, table.—BTR. 8546

3.5.3.

Present Status of Cavitation Research. ROBERT T. KNAPP. *Mech. Eng.,* **76,** 731-734 (1954) Sept.

Review of effect of cavitation on performance of hydraulic devices and losses from mechanical and corrosion damage. Six references.—BTR. 8544

3.5.3

Some Aspects of Erosion-Corrosion Phenomena. G. OKAMOTO AND H. KUBOTA. *Corrosion Engineering* (Japan), **3,** No. 4, 30-31 (1954) Aug.

In order to determine the relative contribution of the suspensoid to the me-

chanical abrasion and electrochemical corrosion of the rotating mild steel specimens, the latter action was eliminated by using zinc anode or using the inhibitor.

The effect of the kind of suspensoid, temperature, and the electrode potential of the corroding specimen were observed. —JSPS. 8699

3.5.3, 5.2.1

Effect of Cathodic Protection to Cavitation-Erosion. G. Okamoto, F. Irie and T. Kato. *Corrosion Engineering* (Japan), 3, No. 5, 34 (1954) October.

Determining the relation between the cathodic current density and the amount of cavitation-erosion, it was confirmed that the cathodic protection was very effective to prevent the cavitation-erosion. The experiment was carried out with the magnetostriction vibration apparatus. Cavitation occurred at the lower surface of mild steel test piece, attached to the lower end of nickel rod in N/20 potassium sulfate solution.—JSPS. 8700

3.5.3, 6.3.6, 6.2.2

Resistance of Metals to Cavitation Erosion in Fresh and Sea Water. (In Russian). K. K. Shalnev. *Doklady Akad. Nauk SSSR*, **95**, No. 2, 229-232 (1954) March 11.

The resistance of brass, bronze and gray cast iron to cavitation erosion in fresh water and in artificial sea water at 25C was determined by exposing the immersed samples for two hours to vibrations of 8000 kc frequency and 0.09 mm amplitude. Judging from weight-loss data, the resistance to cavitation erosion of brass and bronze is essentially determined by their mechanical properties, the chemical composition of the water being of little importance. With gray cast iron, however, corrosion in synthetic sea water exceeded that sustained in fresh water and samples exhibited large and deep erosion cavities which were absent in fresh water. Because these results are considered to be in direct contradiction to the known mechanical and thermodynamic theories of cavitation erosion, it is concluded that the popular view of the mechanism of cavitation erosion is not correct. —PDA. 8625

3.5.8

The Significance of Directional Thickness as Related to Brittle Fracture and Strength in Steels. W. Soete. Paper before Journees d'Automne, October, 1953. *Rev. Met.*, **51**, 813-872; disc., 872 (1954) Dec.

Tests on notched specimens revealed cracks with directionality parallel to mean stress. This produces alteration in state of strain, which ceases to be triaxial. Low strength in direction of thickness encourages incidence of cracks and leads, indirectly, to better behavior of steel from point of view of ductility. Comparison of ratio of strength in direction of thickness to strength in longitudinal or transverse direction, with ratio of corresponding stress, permits definition of transition temp. above which cracks parallel to rolling direction will appear. Banded structure favors appearance of these cracks, which explains improved behavior of such steels, as compared with those without this structure.—INCO. 8701

3.5.8, 1.6

Residual Stresses in Metals and Metal Construction. W. R. Osgood (Editor). Book, 1954, 303 pp. Reinhold Publishing Corp., New York.

This volume was prepared for the U. S. Ship Structures Committee and

comprises chapters by more than 20 authors (American, Belgian, British and German). It has been planned so as to cover all varieties of interest in residual stresses. A useful feature is a final chapter summarizing the views presented.—BNF. 8673

3.5.8, 6.5

Softening of Certain Cold-Worked Metals Under the Action of Fatigue Loads. N. H. POLAKOWSKI AND A. PALCHOUDHURI. Paper before Am. Soc. Testing Materials, 57th Ann. Mtg., June 13-18, 1954. ASTM Preprint No. 74, 1954, 12 pp.

Copper, nickel, aluminum and three of their alloys (including nickel-copper and Ni"O") as well as a non-aging titanium-killed steel were first cold-drawn 20-40% to 0.2-inch in diameter and later were subjected to alternating tension-compression fatigue stressing at frequencies 5500-9500 cpm. Compression tests and Vickers hardness determinations on the fatigued specimens showed more or less pronounced softening in each case. These observations are discussed in the light of previous work on the Bauschinger effect and its manifestations. An interpretation of the present findings is offered on a pure stress-strain basis. Fatigue failure of a cold-worked metal may be attributed to the breakdown of the initially high elastic properties under cyclic strain and to the semi-plastic behavior developed thereby. The cyclic plastic flow would facilitate the coalescence of vacant lattice sits into larger holes, which may act as crack embryos. 22 references.—INCO. 8737

3.5.8, 2.3.7, 3.5.9

Theory of Brittle Fracture and Criteria for Behavior at Low Temperatures. E. R. PARKER. Paper before Am. Soc. Testing Materials, Symp. on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures, 56th Ann. Mtg., Atlantic City, June 28-30, 1953. ASTM Special Technical Pubn. No. 158, 116-130; disc., 131-132 (1954).

Effects of various factors contributing to brittle behavior of steel are discussed. Steel can fail by either of two modes—by shear or by cleavage. Standard unnotched tension specimens fail by shear at normal temperatures but fracture by cleavage without measurable elongation at liquid nitrogen temperature. Notches reduce the ratio of maximum shear to maximum tensile stress so that brittle fractures can occur even at room temperature. Welding tends to provide crack starters because of weld defects such as inclusions, cracks and incomplete penetration. Various tests for determining relative brittleness of steel are compared and meaning of transition temperature is discussed. Brief discussion of service failures is given and correlation between lab tests and service failures is presented. Photomicrographs, graphs and 21 references.—INCO. 8599

3.5.8, 3.5.9

Correlations of Rupture Data for Metals at Elevated Temperatures. R. L. ORR, O. D. SHERBY AND J. E. DORN. *Trans. Am. Soc. Metals,* **46,** 113-128 (1954).

Stress-rupture data for pure metals (aluminum, beryllium, titanium, nickel, niobium, molybdenum) and alloys (aluminum-1.6 magnesium, aluminum-0.1 copper, aluminum-1.1 copper, titanium-1 manganese-1 iron-1 aluminum-1 copper, molybdenum-0.34 niobium, molybdenum-0.87 vanadium) at elevated temperatures are successfully correlated by an equation connecting the applied stress, time to rupture, absolute temperature and activation energy for rupture.—BNF. 8750

3.5.8, 3.5.9

Observations on Elevated-Temperature Tensile Deformation. R. W. GUARD, J. H. KEELER AND S. F. REITER. *J. Metals* (Trans. AIME), Section 2, **6,** No. 2, 226-227 (1954) Feb.

Earlier tests on certain materials have shown a maximum load in the load-elongation curve at relatively small amounts of strain. The reasons are discussed.—BNF. 8480

3.5.8, 3.5.9

Effect of Temperature Cycling on the Rupture Strength of Some High-Temperature Alloys. J. MILLER. Paper before Am. Soc. Testing Materials, Symp. on Effect of Cyclic Heating and Stressing on Metals at Elevated Temperatures, 57th Ann. Mtg., Chicago, June 17, 1954. ASTM Special Technical Pubn. No. 165, 1954, 53-65; disc. 65-66.

Cyclic temperature rupture tests were conducted on four different high-temperature alloys—S816, M252, 16-25-6 and A286. Specimens were subjected to a constant load and three different types of temperature cycles. In rectangular temperature cycle a fraction of time under load was spent at a high temperature and remainder of time under load at a lower temperature, while in sawtooth temperature cycling, load was on specimen continuously and temperature fluctuated an amount ΔT above and below mean temperature. In special temperature cycle, specimens were maintained continuously under stress of 15,000 psi in furnace controlled at 1500F. At regular intervals, temperature of specimen was raised to 1800 F in 60 sec. by passing a heavy electrical current through it and after 60 sec., current was turned off and specimen allowed to cool to furnace temperature. Chemical compositions and heat treatments of alloys are tabulated and stress-rupture curves at several constant temperatures, obtained as basis for calculation and comparison with cyclic temperature tests, are plotted. Size of specimens and method of heating were such that thermal stresses were considered to be negligible. Results of all cyclic temperature tests made are summarized in a graph where calculated rupture life is plotted against actual rupture life. Calculated and actual test values correlate very well, although in general actual values are somewhat lower than calculated values. Graphs, tables, 6 references.—INCO. 8619

3.5.8, 3.7.2, 6.2.1

Notch Ductility: Assessment for Quenched and Tempered Steels. S. DOWNS. Colvilles. Paper before West of Scotland Iron & Steel Inst., Feb. 1954. *Iron & Steel* (London), **17,** 139-140, 144 (1954) April.

Report of experiments demonstrates advantages gained by considering transition temperature rather than result of impact test at atmospheric temperature as criteria of tendency of steels to brittle failure. V-notched Charpy impact tests were made on nickel-chromium-molybdenum steels, in one of which molybdenum was replaced by vanadium. Temperature/impact relationships for quenched and tempered conditions and properties of molybdenum- and vanadium-containing steel were compared. Vanadium should not be used to replace molybdenum in this steel in applications in which notch ductility is likely to be important. Second series of experiments demonstrate manner in which wide variation in impact values of tests broken at atmospheric temperature was explained by position of transition range of steel under test. Nickel content of steel examined was below specification minimum for En. 325: (nickel 1.32 as against 1.5-2%). Investigation of properties in order to determine whether this steel had necessary characteristics to meet requirements of En. 325 specification was made and found that tensile requirements were met, but that Izod impact values showed wide variation. It was an unsuccessful attempt to relate variation in impact values to differences in composition. V-notch Charpy temperature/impact curve is given. In view of relatively poor notch ductility, notch ductility on new En case-hardening steels should be investigated. Experiments on manganese-molybdenum and chromium-molybdenum steels of En 16 and En 19 types present another instance where impact tests at atmospheric temperature give no information regarding relative notch ductility. Results are reproduced. Short note on possible application of methods described to investigate alloy steels with a view to reducing the number of such steels and also conserving alloying elements is included.—INCO. 8444

3.5.8, 6.2.3

Influence of Alternating Stress on Diffusion and Precipitation Phenomena in Unalloyed Steels. H. SCHENCK AND E. SCHMEDTMANN. *Arch. Eisenhuttenwesen,* **25,** 579-588; disc., 588 (1954) Nov.-Dec.

Data on effects of alternating stress on cementation, nitriding and chromizing of steel containing 0.06% carbon, 0.029% manganese, 0.051% phosphorus, 0.025% sulfur, 0.018% nitrogen as function of degree of cold working. Ultrasonic effects in cementation, influence of alternating bend stress and tension-impact on precipitation processes, values for hardness, tensile strength, notch impact, coercive force and electrical resistance, as function of temperature and duration of treatment, and observations on incidence of etching phenomena are included.—INCO. 8695

3.5.8, 6.2.5

The Problem of Thermal Stress Fatigue in Austenitic Steels at Elevated Temperatures. L. F. COFFIN, JR. Am. Soc. Testing Materials, Preprint No. 100a, June, 1954, 20 pp.

Fatigue failures due to localized cyclic thermal straining were simultated in laboratory tests. The results are compared with those obtained from constant temperature tests.—BNF. 8560

3.5.8, 6.4.2

Influence of Exposed Area on Stress-Corrosion Cracking of 24S Aluminum Alloy. W. H. COLNER AND H. T. FRANCIS. Armour Research Foundation. National Advisory Comm. Aeronaut, Tech. Note No. 3292, November, 1954, 22 pp.

Study of area effect, phenomenon whereby small areas show long times to failure while large areas show short times, in 24S aluminum alloy. Effects of stress level, degree of sensitivity of the alloy and hydrogen peroxide concentration in the corrosion medium were studied. Stress levels above 60% of yield strength are uniformly effective in producing stress-corrosion failure. Area effect is most pronounced in specimens having maximum sensitization. Hydrogen peroxide decomposes rapidly in presence of cor-

roding 24S due to cupric ion produced in corrosion. 24S is very sensitive to 1.5-3.5 g/l of hydrogen peroxide; oxygen is not effective when substituted for hydrogen peroxide. Graphs, photomicrographs, illustrations of apparatus, two references. —INCO. 8563

3.5.8, 6.4.2

Internal or Residual Stresses in Wrought Aluminium Alloys and Their Structural Significance. G. Forrest. *J. Royal Aeronaut. Soc.*, **58**, No. 520, 261-276 (1954) April.

Formation of residual stresses (in quenching, drawing and sinking, forming, etc.); control and reduction (by heat treatment, stretching, or bending); practical significance (distortion during machining, effect on behavior under static stress, on stress corrosion and on fatigue resistance); implications for choice of materials. 29 references.—BNF. 8514

3.5.8, 6.4.2, 3.7.3

Structure and Corrosion-Fatigue in Aluminium-Magnesium Alloys. (In French). C. Panseri. *Schweiz. Arch. angew. Wiss. u. Tech.*, **20**, No. 5, 152-156 (1954).

The sensitivity of aluminum-magnesium alloys to stress-corrosion cracking varies with the micro-structure, according to the heat-treatment to which the alloy has been subjected. The effect of such differences in micro-structure on corrosion-fatigue was investigated on aluminum-8% magnesium alloys made from high-purity metals, with some confirmatory experiments on commercial alloys containing 3.5, 5.0 and 7.0% magnesium. Fatigue tests, with and without the application of 3% sodium chloride solution by means of a cotton thread, were carried out on the experimental alloys in the following conditions of heat-treatment: (a) 6 hr. at 440C, quenched, and aged 100 hr. at 100C; (b) 6 hr. at 440C, quenched, stabilized 3 hr. at 300C, furnace-cooled; and (c) 240 hr. at 440C followed by furnace-cooling (~ 1°C hr.). The resistance to corrosion-fatigue was considerably lower than that to normal fatigue, but there was no significant difference between specimens in different conditions of heat-treatment. Metallographic examination showed that fatigue cracks started at grain boundaries at the surface of the specimen in all cases, but that in stabilized specimens the crack became transcrystalline, whereas in the sensitized material the crack remained intercrystalline and branched out in all directions. It was concluded that the slight corrosive attack near the surface of the stabilized material started notches which lowered the fatigue strength to roughly the same extent as the intergranular corrosion in the sensitized material. —MA. 8620

3.5.8, 7.6.4, 4.6.2

Case History of Failure of Marine Boiler Tubes by Stress Corrosion Cracking. R. D. Barer. *Corrosion*, **11**, No. 4, 18-24 (1955) April.

Failures by stress-corrosion cracking of marine boiler tubes are commonly the result of a concentrated caustic solution in contact with stressed boiler metal. Usually the concentration of the caustic results from leakage between seams and around rivets, or capillary action and subsequent evaporation.

A rare example of the same type of failure is one where no seams or crevices exist for concentrating the boiler solution by leakage; this is failure resulting from concentration of the boiler solution right on the steam generating surface of the boiler tube. Details of such a failure are discussed. In particular, it is shown that the attainment of the necessary caustic concentration and stress levels is feasible. It is pointed out that stress need not be as high as is commonly believed.

The mechanism of caustic cracking as understood today is reviewed; that is, electrochemical action aided by stress. In effect, this serves to include caustic cracking among such phenomena as the season-cracking of brass and the stress-corrosion cracking of stainless steel. It is commonly accepted that this type of failure is rare. That it does occur suggests that some thought might be directed to preventing channelling by hot gases and to alternative chemical treatments which do not rely on caustic. 8747

3.5.8, 8.9.1, 6.4.1, 1.3

Fatigue in Aircraft Structures. J. H. Molineux. *J. Birmingham Met. Soc.*, **34**, No. 1, 28-47 (1954) March.

A survey based on 68 references. Metallurgical factors influencing the "safe life" of aircraft structures. Metallographic and X-ray observation of changes occurring in light alloys during fatigue; theories of fatigue.—BNF. 8604

3.5.9, 1.5, 6.1

Materials for High Temperature Service. Materials & Methods Manual No. 104. H. R. Clauser. *Materials & Methods*, **39**, No. 4, 117-132 (1954) April.

A survey of materials used at temperatures above 150C including superalloys, ferrous metals, light metals, ceramics and cermets, plastics, copper and alloys. The superalloys include cobalt and alloys, nickel and alloys, chromium and molybdenum, with a list of compositions.—BNF. 8558

3.5.9, 3.7.2

Metals for Low Temperature. W. L. Nelson. *Oil Gas J.*, **52**, No. 49, 163 (1954) April 12.

Single-phase or solid-solution alloys such as the nickel and manganese (or copper) iron alloys; nickel or manganese steels; austenitic chromium-nickel steels (low carbon); Monel, Inconel, etc.; and pure metals, are all suited for low-temperature strength or ductility. Approximate impact strengths of these and other (includes nickel cast iron, Ni-Resist, 18-8, H Monel and nickel) materials at low temperatures are tabulated. Minute amounts of impurities or alloying agents are detmental to low-temperature shock resistance.—INCO. 8601

3.5.9, 5.3.2, 5.4.2

Special Coatings for Metals Used at High Temperatures. A. H. Sully. *Product Eng.*, **25**, No. 1, 135-141 (1954) Jan.

Sully discusses protective coatings in three categories: i) Diffusion coatings of aluminum, silicon, and chromium—aluminum is applied to iron-base materials in a variety of ways including spraying and dipping. Silicon and chromium are usually applied by heating the material to be coated in contact with a halide. Chromium coatings can be improved by introducing silicon and aluminum halides into the treating atmosphere. ii) Refractory coatings.—A combination of a refractory material is used with a vitreous enamel. It is essential that the coefficient of expansion of the coating matches that of the metal. iii) Low-emissivity coatings to reduce heat transfer by radiation. The coating is fundamentally similar to ii), but greater thicknesses are usually necessary. The coatings are usually more porous and do not confer a high oxidation-resistance.—MA. 8743

3.6 Electrochemical Effects

3.6.6

A Note on the Use of Electrode Potentials for the Estimation of Corrosion due to Dissimilar Metal Contact. G. Mole. Electrical Research Assoc., Tech. Rep. O/T11, January, 1954, 5 pp. Available from British Electrical and Allied Industries Research Association, Thorncroft Manor, Dorking Road, Leatherhead, Surrey.

Brief discussion of corrosion due to dissimilar metal contacts, with a table indicating in general terms combinations to be avoided. Refers also to the use of Pourbaix's potential pH diagrams.—BNF. 8612

3.6.6, 6.3.15, 6.4.2, 6.2.5

Corrosion of Stainless Steel and Aluminium Alloys in Contact with Titanium. C. Braithwaite. Royal Aircraft Establishment, Farnborough, Hants (England), (RAE-TN-MET-192), Feb., 1954, 19 pp.

Titanium samples consisting of 1-inch diameter discs, sheet and ½-inch diameter threaded bar were placed in contact with stainless steel DTD 166 and aluminum alloys DTD 603 and DTD 610 and exposed to the intermittent seawater spray test for one year. Each titanum sample showed extremely good corrosion resistance by itself or when coupled to itself or when coupled to stainless steel or aluminum alloy. Slight corrosion of stainless steel occurred inside the joints. There were only slight signs of corrosion of the aluminum alloy sheets before opening the joints. It was found that serious corrosion of the aluminum had occurred at the interface. Joints wet assembled with pigmented jointing compound DTD 369A showed negligible corrosion. It is recommended that wherever possible joints between titanium and other metals should be wet assembled with DTD 369A and the exterior of the joints should be painted. Aluminum alloys should be anodized. (auth).—NSA. 8561

3.6.7, 4.5.3, 5.2.1

Extrinsic Line Current Fluctuations Seriously Restrict Progress of Coating Conductance Surveys on Large Trunk Line. G. I. Russell and L. B. Nelson. *Corrosion*, **10**, No. 11, 400 (1954) Nov.

Line currents of unknown origin fluctuating as much as 20 amperes in upstream and downstream directions necessitated averaging from 20 to 30 measurements to get one of desired accuracy during coating conductance surveys on Trans-Mountain Oil Pipe Line Company's pipe line. The author postulates these currents may be of the same nature as those observed on other Canadian pipe lines and on lines in Texas, Oklahoma and Missouri, as well as on power systems in Canada and the United States. They are popularly attributed to sun spots, but may be due also to large adjacent bodies of ore. The currents make it extremely difficult for engineers to make reliable electrolysis surveys or tests of cathodic protection systems. 8629

3.6.8

Electrochemical Dissolution of a Metal in Presence of an Anion That Precipitates the Metallic Cation Formed. Equation of Polarization Curve. (In French). J. Badoz-Lambling. *Bull. soc. chim. France*, No. 3, 370-375 (1954) March.

Studies of silver halogenides were in qualitative agreement with established

equations. Tables, graphs. 21 references. —BTR. 8403

3.6.8, 3.4.8, 3.4.7

Hydrogen Overvoltage on Bright Platinum. Part II. pH and Salt Effects in Acid, Neutral, and Alkaline Solutions. Sigmund Schuldiner. *J. Electrochem. Soc.*, **101**, No. 8, 426-432 (1954); Cf. *ibid.*, **99**, 488-494 (1952) December.

The effects of pH over the range 0.5-12.1 and of added Na^+ and NH^-_4 were determined. To avoid contamination, a Teflon cell was used. Relative rates of overall hydrogen-producing reactions at low current density were determined for the solutions studied. Mechanisms of hydrogen overvoltage in these solutions are discussed.—MA. 8669

3.6.9, 5.2.1, 4.5.3

Electrical Techniques for Combating Underground Corrosion by Stray Electric Current. G. Mole. *Corrosion Technology*, **1**, No. 8, 280-285 (1954) October.

Brief review of the existing techniques for the survey and control of stray current corrosion. Measurement of current flowing in cable sheath or pipe, measurement of current density in the soil, measurement of current emission, measurement of potential and interpretation of electrical measurements are discussed. Cathodic protection, an important method of control of underground structures, is covered. Diagrams, graphs and 24 references.—INCO. 8670

3.7 Metallurgical Effects

3.7.2, 6.2.4

Effect of Boron on the Impact Properties of Quenched and Tempered Steels. H. Schwartzbart and J. P. Sheehan. Paper before Am. Soc. Testing Materials, Symp. on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures, 56th Ann. Mtg., Atlantic City, June 28-30, 1953. ASTM Special Technical Pubn. No. 158, 332-343; disc., 343-344, 1954.

Effect of boron on impact properties of quenched and tempered 2345 (containing 3.5% nickel) and 8120 (containing 0.41% nickel) steels were determined. Each experimental heat contained a different amount of boron from 0-0.005%. Addition of boron increased hardenability to a large extent as indicated by the Jominy curves. Present investigation consisted of two phases: the effect of boron on the variation of impact properties with tempering temperature; and the effect of boron on temper brittleness. Photomicrographs, tables, graphs and 14 references.—INCO. 8647

3.7.2, 6.3.10

Rare-Earths in Metallurgy. H. Evans. Paper before Birmingham Met. Soc. *Metal Ind.*, **85**, No. 18, 365-367, 374 (1954) Oct. 29.

History, occurrence and extraction, properties and applications of the rare-earth metals. In the form of an indeterminate mixture, Mischmetall, they are important addition agents for prolonging the life of nickel-chromium alloys. Zirconium is used as an alternative to the rare-earth metals in some nickel-chromium alloys. A graph shows influences of varying amounts of addition agents on the life at 1050 C of iron-free 80-20 nickel-chromium alloys and the effect of rare-earth metal content on the life of 80% nickel-20% chromium alloy wires is tabulated. Photomicrographs, tables, graphs, 10 references.—INCO. 8527

3.7.2, 6.5

Beryllium as an Alloying Addition. L. David. *Metallurgia*, **50**, No. 301, 236-238 (1954) Nov.

The use of beryllium in alloys of magnesium, aluminum, copper and nickel. Properties, fabrication and composition of beryllium-copper wrought and casting alloys are discussed and typical properties of wrought beryllium-copper alloys are tabulated. Important applications of beryllium-copper alloys include current-carrying members in electrical equipment, components in electronic devices and welding electrodes. Use of the alloy in the automotive, aviation and machinery industries is constantly increasing. A beryllium-nickel alloy (with 2.75% nickel) combining good corrosion resistance and high strength is used in the production of small detailed investment castings. A table lists minimum physical properties of some cast alloys including beryllium-nickel and beryllium-copper.—INCO. 8534

3.7.3

Improved Rods and Techniques Overcome Crack Sensitivity in Magnet Steel Welds. J. J. Obrzut. *Iron Age*, **174**, No. 18, 90-91 (1954) October 28.

EutecTrode 680 welding rod is used to join cast steel case of an electromagnet to the cast manganese-steel lifting face because it produces welds that are free of crack sensitivity and have high corrosion resistance, impact resistance and adequate strength. High nickel content in alloy rod improves fluidity. Welding process is briefly discussed.—INCO. 8607

3.7.3

Development of Brazing Alloys. Third Quarterly Progress Report Covering the Period From May 15, 1954 to August 15, 1954. Forbes M. Miller and Homer S. Gonser. Research Lab., Wall Colmonoy Corp., Contract AF 33 (616)-2287, 20 pp.

A number of brazing alloys on the base metals Inconel and 304 stainless steel were tested for tensile and shear strengths. Oxidation tests were also made. The results of the tests are tabulated.—NSA. 8592

3.7.3

Heat Treatment of Aircraft Gears in Continuous Furnaces. C. A. Payntor. Dana Corp. *Steel Processing*, **40**, No. 9, 585-590 (1954) Sept.

Rigid control within extremely close tolerances is possible with highly uniform consistency in critical precision aircraft gears and parts using continuous gas-fired controlled atmosphere furnaces. Wide range of metallurgical results are possible with minimum handling, different steel analyses are processed at the same time although carburizing cycles are automatic and range of case depths is obtained by regulating cycle intervals on work trays. Unique furnace atmosphere arrangement, which produces suitable case C gradients, is described. Group of typical gears and parts of AMS 6260 and 6263 high nickel steel are used as examples for close tolerances and rigid specifications. After carburizing, gears are slowly cooled to room temperature before heating for hardening. Parts often cannot be re-heat treated if accurate results are not obtained the first time. Table shows typical specifications and tolerances for heat treated cam gear, drive gear, mixed gear and impeller shaft of AMS 6260 and 6263. Illustrations, photomicrographs.—INCO. 8593

3.7.3

High Temperature Brazing: The Application of Corrosion-Resistant and Heat-Resistant Alloys to the Fabrication of Sheet-Metal Assemblies. G. D. Cremer, F. J. Filippi and R. S. Mueller. *Aircraft Prod.*, **16**, No. 2, 76-81 (1954) Feb.

Paper presented at SAE National Aeronautic Meeting, Los Angeles. Reviews various brazing materials (molybdenum-braze, silicon, copper, silver-manganese, manganese-nickel, silver-pladinum, pladnium-nickel, Solabraze (nickel-manganese-chromium-boron-silicon) alloys, Nicrobraz) with examples of their use. Also infiltration brazing, construction of stainless steel honeycomb material (Hexcel and Squarcel) by brazing, etc.—BNF. 8408

3.7.3, 1.6, 3.7.4

Fundamentals of the Working of Metals. G. Sachs. Book, 158 pp., 1954, Pergamon Press Ltd., London.

The book, an elementary introduction to metal working processes, comprises a number of articles previously published in the American periodical, The Modern Industrial Press. The author's object is to describe the basic principles of metallurgy which determine how metals behave on mechanical working, so that the reader will understand the success or failure of forming operations in particular cases. Though it is an elementary treatment, the author has tried not to simplify his explanations to the extent of making them misleading. The chapters deal with the effects of temperature and speed of working; relations between composition, phase changes and forming characteristics; effects of grain structure; basic metal forming methods; and progressive fabrication.—ZDA. 8656

3.7.3, 3.6.6

Stops Galvanic Corrosion. *Modern Metals*, **10**, No. 6, 84, 86 (1954) July.

To protect joints of aluminum and dissimilar metals from galvanic corrosion, a new insertion material has been developed by Winn & Coales, Ltd., Denso House, Chapel Road, London, England. It is called Densochrome tape and is claimed to provide a simple means of protecting bimetallic joints. It is impregnated and coated on both sides with a stable chemical compound and contains 20% by weight metallic chromate inhibitor. It is self-adhesive, easily applied, non-absorbent, non-hardening and highly resistant to acids, alkalies and salts.—ALL. 8665

3.7.3, 3.7.2, 6.2.4

Effect of Metallurgical Structures on the Impact Properties of Steels. J. A. Rinebolt. Paper before Am. Soc. Testing Materials, Symp. on Effect of Temperature on the Brittle Behavior of Metals with Particular Reference to Low Temperatures, 56th Ann. Mtg., Atlantic City, June 28-30, 1953. ASTM Special Technical Pubn. No. 158, 203-214; disc., 215 (1954).

Investigation was intended to show the eeffct of three types of heat treatment on the notch toughness and tensile properties of low-alloy steels and to show the effect of these treatments in the presence of various alloying elements, including carbon, manganese, nickel, phosphorus and silicon. Three heat treatments were used to yield a pearlite structure and two spheroidite structures. Transition temperature of all three structures was raised by the addition of carbon, phosphorus and silicon and lowered by manganese and nickel. Tables, photo-

micrographs, graphs and 6 references.—INCO. 8709

3.7.3, 5.3.2
How About Fabricating Zinc Coated Steels? L. F. Spencer. Mag. of Tooling and Production. *Tool and Die J.*, **19**, No. 12, 41-43, 66, 68, 74-75, 104 (1954) Mar.

Forming operations are not easily carried out on ordinary galvanized steel owing to the presence of a brittle iron-zinc layer. The Sendzimer process which eliminates this brittle layer is described in detail and several examples of forming operations carried out on the sheet are discussed. Recommendations for painting, storing and removing white rust from the zinc coated sheet are given and the various methods for welding and soldering the sheet are outlined. The continuity of the article from p. 68 to 74 seems to be broken.—ZDA. 8715

3.7.3, 5.3.4
Multiple Electrode Welding by "Unionmelt" Process. D. E. Knight. Linde Air Prods. Co. Paper before Am. Welding Soc., 34th Nat. Falls Mtg., Cleveland, October 19-23, 1953. *Welding J.*, **33**, No. 4, 303-312 (1954) April.

Submerged melt welding, suitable for many different welding applications is discussed. Series-tandem technique is valuable in the cladding of surfaces. An example is given of the use of this method in the application of a layer of stainless steel to a large forging to be used in the chemical industry. Cross section of a carbon steel seat ring which was clad with Hastelloy B is shown. Illustrations.—INCO. 8552

3.7.3, 6.2.2, 3.5.8
The Influence of Surface Rolling on the Fatigue Properties of Flake Graphite and Nodular Graphite Cast Irons. Research Rept. No. 392. G. N. J. Gilbert and K. B. Palmer. *J. Res. and Dev., Brit. Cast Iron Res. Assoc.*, **5**, No. 8, 447-464 (1954) Oct.

Effects of surface rolling on the fatigue strength of 45° V-notched specimens of flake graphite and nodular cast irons was investigated. Increases in fatigue limit of 20% in a pearlitic flake graphite cast iron and over 190% in a ferritic nodular iron were obtained. It appears that the increase in fatigue limit obtained depends on the ductility of the material and in this respect nodular irons are superior to flake graphite cast irons and ferritic irons are superior to pearlitic irons. Surface rolling also results in an increase in fatigue life at stresses above the fatigue limit. Photomicrographs, tables, graphs and two references.—INCO. 8525

3.7.3, 6.2.5
On Subzero-Worked 18-8 Stainless Steels (2nd report). Corrosion Resistivity Against Acid Solutions. R. Odaka. *J. Japan Inst. Metals*, **18**, No. 7, 396-400 (1954) July.

Corrosion tests were carried out on statically compressed stainless steel containing 2.00% manganese, 10.26% nickel, 18.11% chromium and 1.52% molybdenum. The working was done at 20 and −183 degree. Since the Md point of steel lies below 20 degrees the influence of the working and that of martensite formed by subzero-working on the corrosion resistivity of such steel could be discussed separately. The corrosives used were aqueous solutions of 62.7% nitric acid, 5% sulfuric acid, 20% sulfuric acid and 2.4% hydrochloric acid in boiling conditions. Main results obtained are as follows: 1) In the solutions of 62.7% nitric

acid and 5% sulfuric acid, all specimens, except one tempered at 600 degrees which showed low resistivity, became passive; and the resistivity was found to be almost independent of the working and the amount of martensite. 2) In the solution of 20% sulfuric acid, specimens were strongly attacked and the more the degree of working and the amount of martensite, the more strongly. The resistivity was improved by tempering up to 400 degrees, but was markedly reduced by tempering at 600 degrees. 3) In the solution of 2.4% hydrochloric acid, little influence of working and much influence of martensite amount was found. The specimens including martensite showed lower resistivity than those free from martensite and by tempering they behaved as in the case of 20% sulfuric acid. On the other hand, martensite-free specimens, even in a severely worked state, became more stable against hydrochloric acid solution by tempering up to 600 degrees. 4) Neither working nor strain-induced martensite affects the tendency to become passive. Hence the resistivity of the steel against concentrated nitric acid and dilute sulfuric acid is scarcely influenced by working, but under non-passive state as in the case of the corrosion in hydrochloric acid, it is reduced by working, especially by the formation of martensite caused by the working.—JSPS. 8617

3.7.3, 6.2.5

Metallurgical Aspects of Welding Precipitation-Hardening Stainless Steels. C. W. FUNK AND M. J. GRANGER. Aerojet-General Corp. *Welding J.*, **33**, No. 10, 496s-508s (1954) October.

Comparison of aircraft materials of construction with respect to yield strength at weight ratio at ambient and elevated temperatures, corrosion-resistance and characteristics during fabrication. Mechanical properties and structural changes are discussed for stainless W, 17-7PH, 17-4PH and V2B. Effect of microstructure on mechanical properties and response to alloying elements and heat treatment are discussed. Mechanisms and procedures of annealing, transformation and precipitation-hardening relative to improved ductility in welded joints are discussed. Observations at Aerojet-Gen. Corp. included chemical analysis of weldments, studies of porosity, abnormalities in heat-affected zone and nonfusion effects. Chemical composition of 17-7PH (high aluminum content) is responsible for nonfusion defects, while variation of composition influences response of the alloy to heat treatment. Photomicrographs, tables, graphs, 13 references.—INCO. 8549

3.7.3, 6.4.2

Hot Working of Light Alloys. (In German). F. PLATTNER. *Z. Metallkunde*, **45**, No. 5, 253-256 (1954) May.

Rolling: use of vertical rolls; emulsion coatings to protect the material; avoiding tendency to earing. Extrusion: dies for speeding up the process; cooling behavior of different Al alloys.—BNF. 8688

3.7.3, 6.4.2, 7.7

New Tin-Depositing Flux for Soldering Aluminum. DONALD C. BURCH AND ROBERT L. SIMPKINS. *Materials and Methods*, **40**, No. 2, 86-89 (1954) August.

The SX Aluma-Flux for soldering aluminum is described. It is a stannous chloride base reaction flux and reacts with aluminum oxide and the underlying aluminum. Metallic tin is deposited on the aluminum surface and aluminum chloride is formed which volatilizes, leaving no corrosive residue. Any unreacted flux is easily washed away with water. The tin that is deposited temporarily prevents the formation of a new layer of aluminum oxide and then alloys readily with both the aluminum and the solder. The flux and a suitable solder make excellent butt joints and lap joints between aluminum bars, sheet and plate and also excellent electrical connections on aluminum wires and cable. Although the flux is normally used as a powder, it may be kept molten for more convenient use. It has been maintained molten at 450F for three weeks without noticeable effect on its fluxing ability, and with but minor change in composition. Zinc-tin alloys with from 20 to 90% tin, and zinc-aluminum alloys with about 5% aluminum make satisfactory joints when applied with this flux. The 70% zinc-30% tin alloy has been selected as offering the best over-all combination of properties and convenience in application. Half-inch-square bars were butt soldered and broken to estimate the tensile strength of the soldered joints. In addition, joints in 0.064-inch thick sheet, cut to 0.860-inch wide and lapped exactly 3/16-inch were made to determine shear strength and corrosion resistance. Butt joints in ½-inch diameter rod of 2S aluminum were wrapped around a 1-inch mandrel without any sign of cracking. Joints in this material, being stronger than the stock, could not be broken, either as butt or lap joints. Corrosion resistance and electrical resistance were tested. Because of their greater hardness, 61S lugs would be preferred to 2S lugs for practical applications. Joints in 3S aluminum, which were made with various commercial solders and fluxes, were exposed to an accelerated corrosion test in the humidity cabinet. At the end of two weeks, all but one of the joints made with other commercial fluxes and solders had fallen apart. The stannous chloride base flux may be used in torch or furnace brazing; copious fumes are evolved, making good ventilation essential.—ALL. 8507

3.7.3, 6.4.4

Heat Treatment of Cast Magnesium Alloy ML-5 in Protective Gases. (In Russian). I. A. MAKOLKIN AND S. N. SHESTAKOV. *J. Applied Chem.* (Zhur. Priklad. Khim), **27**, No. 4, 421-424 (1954) April.

Effect of heat treatment in air, nitrogen, carbon dioxide and sulfur dioxide on tensile properties of the magnesium-aluminum-manganese alloy ML-5. By raising the temperature from 415 to 425C, heat treatment time can be reduced without any harmful effects.—BNF. 8676

3.7.4, 4.3.2, 3.4.3

Investigations on Electrolyte-Condenser Foils. L. HOLIK AND H. NOWOTNY. *Metall*, **8**, No. 5/6, 180-184 (1954) March.

Different investigations on etched foils showed a distinct dependence of the solution speed on small impurities present in the etching fluid. Even impurities present in the metal influenced the solution speed. The first test series was carried out with pure hydrochloric acid. The specific capacity was measured in dependence on the weight loss at different acid concentrations. It was shown that the nature of attack depends on the acid concentration. After reaching a certain concentration a stabilization of the etching action was observed. The second test series was made with hydrochloric acid containing aluminum chloride. The presence of aluminum chloride lowered the specific capacity and improved the reaction speed. It has been shown that the structure of the metal (grain size, texture) influences the attack of aluminum by acids. In cubic face centered metals, such as aluminum, the slip planes are octahedral planes; therefore the slip lines represent lines of intersection between the octahedral planes and the metal surface. Slip bands are made visible by bending of the electrolytically polished foil in different directions and subsequent etching in diluted hydrochloric acid. X-ray textures show different structures for the interior of the foil and its surface. This seems to have a marked influence on the etching behavior. In foils with "asymmetric" orientation the etching speed was higher than in foils with "symmetric" orientation of the crystallites. Electrolytic etching is described.—ALL. 8443

3.8 Miscellaneous Principles

3.8.2, 3.8.4

The Thermodynamics of Electrochemical Processes. T. G. OWE BERG. *J. chim. phys.*, **51**, No. 5, 225-232 (1954).

The second law of thermodynamics is applied to the discussion of irreversible processes, e.g. electrolytic conduction and electrochemical potential and expressions are derived for contact, transfer and diffusion potentials between two solutions in contact. In certain simple cases, the theoretical and experimental values are sufficiently in agreement to confirm the validity of the formulae, but in other cases, e.g. contact between sulfuric acid and potassium sulfate, knowledge of the chemical reactions occurring is lacking, so that comparison between theoretical and experimental results is impossible. 22 references.—MA. 8723

3.8.3

Phenomena of Passivity of Metals and Alloys (In Italian). R. PIONTELLI. *Metallurgia Italiana*, **46**, special supplement to No. 5, 5-28 (1954) May.

Theoretical study. Tables, charts. 9 references.—BTR. 8738

3.8.3, 3.6.5, 2.3.5

The Break-Through Potential of Passive Iron-Chromium Alloys in Sulfate Solutions. G. MASING, T. HEUMANN AND H. JESPER. *Arch. Eisenhuttenw.*, **25**, 169-179; disc., 179-180 (1954) Mar./Apr.

Detailed account of experiments on anodic behavior of chromium, iron, iron-chromium alloys, platinum and 18/9 chromium-nickel steel. Iron-chromium alloys contained 4.5, 10.5, 12.5, 17.5, 22 and 29.5% chromium. Measurements were made of current-density-potential-curves in 1N potassium sulfate solution. 0.1N and 1N sulfuric acid at 20, 45 and 70C. Data on course of potential as function of time, effects of chromium additions to iron on evolution of oxygen and solubility of the alloys and discussion of phenomenon characterized as secondary passivity are included.—INCO. 8429

3.8.4

Dissolution of Various Metals in Contact with Rotating Platinum Electrodes. (In German). TIHOMIL MARKOVIC. *Werkstoffe u. Korrosion*, **5**, No. 4, 121-123 (1954) April.

Investigation of influence of cathode surface area on rate of corrosion. Metals investigated include lead, zinc, iron and aluminum. Linear relation was found between surface areas up to 10 sq. mm. or up to 20 sq. mm. if current density remains constant. Distribution of cathode

and anode spots and effects of addition of hydrogen peroxide in re-initiating cathodically-inhibited corrosion are discussed.—INCO. 8418

3.8.4, 5.8.3

The Dissolution of Metal Single Crystals in Acids: Determined for Aluminium, Zinc and Lead. (In Italian). G. BOLOGNESI. *Metallurgia Italiana*, **46**, No. 1, 9-12 (1954) January.

Experiments were carried out on spherical specimens in hydrochloric acid solutions. The reproducibility of such experiments, where no grain boundaries are involved, is stressed and author proposes to use this method to study the effect of inhibitors.—BNF. 8402

3.8.4, 4.3.2, 6.2.2, 6.4.2

The Rates of Solution of Iron and Aluminium in Aqueous Solutions of Hydrochloric Acid. T. G. OWE BERG. *J. Chim. Phys.*, **51**, No. 4, 141-160 (1954).

The velocity of solution, ν, of impure iron in aqueous solution of hydrochloric acid of strength 1-13N, at temperatures, T = 0—65C, was found to be given by the formula: $\nu = AC^2 \propto^{1/2} T^{1/2}/C \exp(-E/RT)$, where C and c are the concentrations of hydrochloric acid and water, respectively, and $\propto$ is the degree of ionization of the acid. The activation energy of the process, E, is given by: E = 15.0-0.445c kg. cal./mole. The process of solution is controlled by the hydrolysis of ferrous chloride. The part of the surface covered by ferrous chloride is determined by equilibrium between reactions occurring at the surface and in the solution and α the square root of the velocity of adsorption of the ionized hydrochloric acid molecule. In the case of impure aluminum, ν obeys different laws in different concentration ranges. In one range $\nu \propto C^2$, and is controlled by solution of aluminum hydroxide; E is independent of c. At higher temperatures and concentrations $\nu \propto c$ and is controlled by removal of adsorbed hydrogen from the metal surface. At c = 10.1N, ν decreases suddenly by a factor of 10-100 owing to adsorption of non-ionized hydrochloric acid molecules by the metal, these molecules not reacting with the aluminum. 9 references.—MA. 8731

4. CORROSIVE ENVIRONMENTS

4.2 Atmospheric

4.2.1, 8.1.2, 1.2.2

The Atmospheric Corrosion of Architectural Meals. HUGH P. GODARD. Aluminium Laboratories, Ltd., Kingston, Ontario. *Eng. J.* (Canada), **36**, 844-855 (1954) July.

Data on comparative corrosion rates in rural, marine, and industrial atmospheres show that aluminum corrodes least, although the rates cited for this metal are too low, except for rural atmospheres, because they are based on uniform corrosion and do not take pitting into account. The rates are highest for zinc. Copper and lead have approximately equal corrosion rates in rural and marine atmospheres. The rates are determined on the basis of weight loss, calculated in mils per yr. (mpy).

The relative cost of corrosion for the different metals, based on quotations for metal roofing sheet in 1000-lb. lots in April, 1953, in the Montreal area is made from the following formula:

$$\$/1000 \text{ sq. ft./yr.} = \frac{(1000)\ (\$/\text{sq. ft.})}{(\text{mils thickness})}$$
(corrosion rate in mpy)

In rural atmospheres the cost for aluminum is by far the lowest of any of the metals. The cost for aluminum in marine atmospheres is slightly higher than that for industrial atmospheres. The cost figure for copper is equal in rural and marine atmospheres and higher in industrial atmospheres. Aluminum is about equivalent to copper in marine atmospheres. In tropical marine atmospheres, aluminum is similar to lead. In marine atmospheres, the cost for lead and copper is considerably less than that for galvanized steel. In industrial atmospheres, lead shows the lowest cost figure, with aluminum next. Steel shows the highest cost figure in all three types of atmospheres, followed by galvanized steel.—PDA. 8160

4.2.1, 6.4.2

Aluminium Roofing in Severe Industrial Conditions. Northern Aluminium Co. Ltd. Brochure, June, 1954, 9 pp.; *Light Metals*, **17**, No. 196, 227-230 (1954) July; *Mech. World*, **134**, 300-303 (1954) July.

Surveys published data on the weathering characteristics of aluminum compared with other metals, in marine, industrial and rural atmospheres and gives examples of the service being obtained from aluminum roofs and walls in various gas works and other industrial premises.—BNF. 8664

4.2.3, 8.9.1, 3.2.2

Corrosion of Aluminum Alloys by Ex-

haust Gases—Topic of the Month. F. M. REINHART. *Corrosion,* **10,** No. 12, 421 (1954) Dec.

Severe corrosion developed on both commercial and military aircraft wing skin sheets made of 75S-T6, Clad 75S-T6 and Clad 24S-T3. Corrosion is of intergranular type accompanied by exfoliation and usually originates adjacent to rivets and at joints on the area of the wings which are swept by exhaust gases from engines. Products of combustion, one of which is lead bromide, deposit and act as sites for corrosive attack. Another contributing factor is the condensate itself, which, containing dissolved gases, is a good electrolyte and maye be active chemically.—INCO. 8719

4.2.7

Corrosion of Metals and Metal Coatings in Tropical and Sub-Tropical Climates. (In German). W. MACHU. *Werkstoffe u. Korrosion,* **5,** No. 10, 395-398 (1954) Oct.

Temperature fluctuations; condensation; corrosion of galvanized coatings in Egypt (discussed in detail, including effect of chlorides carried by wind from desert sand), of various available metals and coatings. Author recommends copper and its alloys; silver, lead; nickel or nickel-chromium coatings of sufficient thickness and stainless steels.—BNF. 8586

4.3 Chemicals, Inorganic

4.3.2, 6.2.5, 6.4.2, 2.4.2

Corrosion and Erosion-Corrosion of Some Metals and Alloys by Strong Nitric Acid. J. F. WILLGING, J. P. HIRTH, F. H. BECK AND M. G. FONTANA. *Corrosion,* **11,** No. 2, 31-39 (1955) February.

The corrosion and erosion-corrosion resistance of several stainless steels and aluminum alloys in strong nitric acid in the temperature range of room temperature to 160 F were investigated. In general the stainless steels show a marked increase in corrosion with increasing temperature. Galvanic couple systems of aluminum and stainless steel show the stainless steel to be protected by the aluminum which acts as a sacrificial anode in strong nitric acid. Polarization studies on aluminum and stainless steel provide some interesting information concerning the corrosion behavior of the aluminum-stainless steel couple system.

Erosion-corrosion tests show that the rate of attack on stainless steel decreases with increasing velocity of acid flow; the rate of attack on aluminum tends to increase with increasing velocity of acid flow. Experiments were conducted on both rotating specimens and on stationary specimens in a system involving a flowing solution.

A detailed description of the equipment used for the polarization and the erosion-corrosion studies is included. 8533

4.3.5

Selection of Piping for Chlorine Services. J. A. MINSER. *Crane Valve World,* **51,** No. 2, 45-46 (1954).

Materials recommended are iron and steel for dry or liquid chlorine, Monel and Hastelloy C for moist chlorine (including valves open to the atmosphere). Care must be taken in the design if Monel is used.—BNF. 8668

4.3.3, 7.1, 5.8.2, 3.5.9

Corrosion Aspects of the Vanadium Problem in Gas Turbines. S. H. FREDERICK AND T. F. EDEN. *Corrosion,* **11,** No. 1, 35-49 (1955) Jan., *Proc. Inst. Mech. Engrs.,* **168,** No. 3, 125-134v (1954) March.

The effect of vanadium pentoxide and mixtures of vanadium pentoxide and sodium sulfate on turbine fouling and corrosion is discussed. Laboratory tests have shown that none of the commercially available alloys is immune from attack when these mixtures are molten, that is, at temperatures above 650C. Nickel base heat resisting alloys of the Nimonic type offer higher resistance to attack than the austenitic steels and some degree of protection is afforded by electro-deposited coatings of chromium.

Steels and heat-resisting alloys are not attacked to any significant extent at temperatures below the melting point of the ash, but copper base alloys suffer considerable corrosion at temperatures as low as 500C.

A detailed investigation of the effect of additives on the corrosion rate of vanadium pentoxide-sodium sulfate ashes indicates that corrosion can be considerably reduced and that such a method of approach is promising. Suitable additions may be made by a mixture of oil or water soluble materials with the fuel, by suspension in the fuel, or by separate injection into the combustion chamber with the object of reducing corrosion and deposition.

Laboratory corrosion tests, using ash additives such as zinc oxide, aluminum oxide and kieselguhr, have shown that the rate of attack can be greatly accelerated if the additive is present in certain critical proportions, but when this is exceeded, corrosion is considerably reduced. With magnesium oxide, however, no such increase in attack was noted. Rig tests have confirmed some of the beneficial effects of additives. 8509

4.3.5

Corrosion of Metals of Construction by Alternate Exposure to Liquid and Gaseous Fluorine. R. M. GUNDZIK AND C. E. FEILER. National Advisory Committee for Aeronautics, Tech. Note No. 3333, Dec., 1954, 10 pp.

Quantitative investigation of corrosion of 3S-O and 52S-O aluminum, AISI 347 and 321 stainless steels, "A" nickel and low-leaded brass by alternate exposure to liquid and gaseous fluorine for periods up to 3½ months was made. For storage and handling purposes, the change in weight of each of the metals was negligible under test conditions. No difference was observed between portions exposed to gaseous fluorine only and those exposed alternately to liquid and gas. In the case of nickel slight intergranular corrosion was observed. Tables, photomicrographs, 4 references.—INCO. 8467

4.4 Chemicals, Organic

4.4.7, 3.7.3, 8.8.5

Machine Tool Corrosion by Soluble Cutting Oils. Pt. II. *Product Finishing,* **7,** 74-86 (1954) Jan.

Discusses results of investigation of the corrosive action of eleven oils on cast iron similar to that used in machine tool construction. Tables, graphs.—BTR. 8740

4.5 Soil

4.5.1

Geological Cells: their Role in Certain Corrosion Phenomena. (In French). M. D. PETROCOKINO. *Corrosion et Anti-Corrosion;* **2;** Nos. 2, 3; 69-75, 99-105 (1954) March-April, May-June.

Electrochemical cells formed by buried metal structures running through different soils may cause corrosion. First part discusses electrical aspects of such cells and geophysical methods of measuring soil resistance; second part, mechanism of such corrosion, with examples.—BNF. 8694

4.5.2, 5.2.2, 3.3.4

Corrosion Due to Mud Banks in River Estuaries. W. S. PATTERSON. *J. Applied Chem.,* **4,** Pt. 4, 661-666 (1954) Dec.

Estuary mud, frequently characterized by high bacterial pollution, is an environment in which corrosion of iron and steel may readily occur. Influence of temperature on corrosion and also the effect of abrasion on protective quality of paint film are examined. Corrosion is very severe under the anaerobic conditions obtained by complete immersion in the mud. Under water-line conditions the phenomenon is more complicated, but corrosion under oxide blisters may be due to bacterial action. It is apparent that sacrificial protection with zinc is effective for steel in polluted mud. Tables and eight references.—INCO. 8609

4.6 Water and Steam

4.6.2, 7.6.4

Boiler Feed Water Treatment for Advanced Steaming Conditions. J. LEICESTER. *Overseas Engr.,* **27,** 206-211 (1954) Jan.

Reports results of research into factors leading to boiler corrosion and deposits. Presents recommendations for feed water conditioning. Diagrams, graphs. Eight references.—BTR. 8526

4.6.2, 7.6.4

Corrosion of Materials in High Temperature Waters. C. J. LANCASTER AND W. L. WILLIAMS. Naval Engineering Experiment Station, Annapolis, EES-040028F, Feb. 9, 1954, 26 pp.

Results are reported on a number of laboratory experiments dealing with the problem of stress-corrosion cracking of austenitic stainless steels in boiler water environments. The data support an earlier conclusion that Navy boiler water treatment inhibits the cracking in materials submerged in the water. However, the treatment is not effective with materials above the liquid level. Cracking could be produced easily in the vapor phase at water temperatures, water compositions and material stress levels of practical interest. In addition, it was demonstrated that this type of cracking could occur in practical applications. The demonstration consisted of an inspection and location of numerous cracks in a stainless steel cyclotherm boiler used for hotel services aboard AM 421 class nonmagnetic mine sweepers. (auth).—NSA. 8537

4.6.4, 4.6.11

Sea Water as an Industrial Coolant. Part I. Operating Conditions. W. B. BROOKS. Dow Chem. Co. *Petroleum Refiner,* **33,** No. 10, 127-130 (1954) Oct.

Discusses corrosion problems involved in using sea water as an industrial coolant, including bacterial corrosion and the corrosion behavior of metals and alloys in sea water. Tables list corrosion rates of different compositions of iron and steel (including 1.3% nickel, .74% chromium, 3% molybdenum, and 2% nickel steel) when immersed in sea water and rela-

tionships between open circuit potentials and corrosion rates of metals (including nickel, stainless Type 410, and Hastelloy C) in sea water flowing at 13 ft. per sec. at 77F. 19 references.—INCO. 8571

4.6.8
C & H Pumps Gas-Laden Corrosive Water from Deep Osceola Lode. *Mining World,* **16,** No. 12, 38-45 (1954) Nov.

Description of the unwatering of the Osceola Lode in Michigan by Calumet & Hecla, Inc. which is believed to be the largest underground dewatering pumping operation in the world. Large concentrations of corrosive chlorides and explosive gases contained in the water entailed additional problems. Monel and bronze pumps and casing coated internally and externally with neoprene were used for greatest corrosion resistance.—INCO. 8605

4.6.12, 7.2, 6.6.8
Plastic Pipe Lines Well. E. S. Moreland. Carlon Products Corp. *Heating, Piping & Air Conditioning,* **26,** No. 8, 92-93 (1954) August.

Disposal well was constructed to dispose of corrosive waste water. Natural ground water flowing from the well contained a high percentage of chlorides and hydrogen sulfide. To prevent corrosion of the wall, the casing was lined with plastic pipe. Provision was made for stainless steel pipe at the surface to avoid any strain and possible breakage of the plastic pipe. Illustrations.—INCO. 8424

4.6.13
Biological Treatment of Cyanides, with and without Sewage. A. E. J. Pettet and E. V. Mills. *J. Applied Chem.,* **4,** No. 8, 434-444 (1954) August.

Experiments on effect of cyanides commonly found in plating wastes on treatment of sewage in percolating filters. Results show that for filters acclimatized to cyanide more than 99% cyanide was destroyed in solution in sewage and in solution in water containing 100 ppm as potassium cyanide or as complexes of zinc or cadmium (for copper or nickel complexes about 75% is destroyed). The action appears to be biological and may offer an alternative pretreatment to chemical oxidation before discharge into a sewer.—BNF. 8685

4.7 Molten Metals and Fused Compounds

4.7
Investigation of Materials for Use in a Heat Transfer System Containing Liquid Lead or Bismuth. Final Report. O. Cutler Shepard, James R. Morgan, and Ralph Parkman. Stanford Univ. School of Mineral Sciences. Contract AT(11-1)-190, Report No. 16 (AECU-2915), June 30, 1954, 31 pp.

Data are reported from studies of the dissolving of iron and chromium from various steels immersed in liquid lead.—NSA. 8652

4.7, 4.3.3, 6.3.10, 2.4.2
A Study of Corrosion and Mass Transfer of Nickel by Molten Sodium Hydroxide. Robert A. Lad and Sidney L. Simon. *Corrosion,* **10,** No. 12, 435-439 (1954) Dec.

The usefulness of nickel as a container material for molten sodium hydroxide is severely hampered at high temperatures by the occurrence of corrosion and mass transfer whenever a temperature gradient is present in the system. Free convection studies at other laboratories and preliminary studies at the National Advisory Committee for Aeronautics Lewis laboratory showed that the amount of mass transfer is strongly affected by variables such as temperature level, temperature gradient, flow conditions, atmosphere and the chemical composition of both the caustic and the nickel. It was found that normal care in the control of these variables resulted in reproducibility of the order of 200 to 300 percent. A free convection test was developed which yielded results reliable to ±10 percent and made it possible to study the effects of the different variables and to investigate the effectiveness of additives. The relations between mass transfer rate and temperature gradient were established in the temperature range 1400-1600F. The effects of additions of a large variety of materials to the caustic were also studied.

Induced flow experiments at velocities up to 15 feet per second were performed in an apparatus which permits independent variation of flow rate and temperature gradient. This system contained no other metal except that under study and required no pump, valves or flowmeter. A variety of additions to the caustic were made for the purpose of comparison with the free convection tests. 8511

4.7, 8.4.5
Studies in the Uranium-Bismuth Fuel System. J. E. Atherton, D. H. Gurinsky, O. F. Kammerer, C. Klamut, M. Silberberg, B. Turovlin and J. Weeks. Chemical Engineering Progress Symposium Ser.

No. 12, Part II, Nuclear Engineering, 23-27 (1954).

Static and dynamic corrosion tests were made on chromium-molybdenum and chromium-silicon steels in contact with liquid bismuth-uranium. Zirconium inhibition studies, a liquid metal convection pot and solubility of iron in liquid bismuth are described.—NSA. 8488

5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2.1

Proposed Methods for Cathodic Protection of Composite Structures. M. Unz. *Corrosion*, **11**, No. 2, 40-43 (1955) Feb.

Separate current drainage systems or special blocking circuits are required for heterogeneous structures which are closely located to each other. This precaution is essential for the elimination of metallic short-circuit paths between the structures, liable to cause dangerous local corrosion currents when the protective circuit is disturbed.

Galvanic anodes used for the protection of parallel pipe and cable lines must therefore be grouped separately. Applied current generators are equipped with rectifier elements to block circulating currents between the components of the plant protected. AC circuits are fitted with separate rectifier units for each section.

Concentric steel ducting is best completely insulated from the metal body contained in it. Where this is not possible as in the case of bore-hole wells, two separate drainage circuits are required with provision for keeping the potentials of the casing and the inner body on the same level.

A further investigation will be published as soon as experience has been gained with the methods suggested. 8459

5.2.1

Determination of Two Basic Parameters of a Long Subterranean Metallic Structure. (In Russian). B. G. Lortkipanidze. *Elektrichestvo*, No. 9, 64-65 (1954) Sept.

Equations for damping coefficient and effective resistance for calculating cathodic protection. Graphs. Three references.—BTR. 8536

5.2.1, 1.2.2

Economic Aspects of Cathodic Protection. (In Italian). T. Nanni and A. Compostella. *Metallurgia Italiana*, **46**, special supplement to No. 5, 98-100 (1954) May.

Economic advantages of cathodic protection. Table. 6 references.—BTR. 8596

5.2.1, 3.6.9, 4.5.3

Solution of Cathodic Protection Interference Problems. Francis W. Ringer. *Corrosion*, **11**, No. 3, 45-52 (1955) March.

When an external source of power with associated ground bed is used to provide cathodic protection to an underground structure, the possibility is presented of creating accelerated corrosion on neighboring structures which are not a part of the cathodic protection system due to the flow of interference currents on these neighboring structures. This article describes a method of obtaining data which will permit the extent of interference to be determined before permanent cathodic protection installations are made. And, if the need for a bond between structures to prevent interference is indicated the bond resistance can be calculated on an engineering basis. Data obtained by the use of this method are of engineering accuracy which can be obtained in minimum of field time, thus eliminating cut and try methods and the need for extensive surveys made before and after permanent installations are completed.

The method was evolved approximately 20 years ago by the late Dr. J. M. Pearson of the Sun Oil Co. in connection with his development of engineering methods for the investigation and control of stray currents on underground structures. Since cathodic protection interference currents are of the same nature as stray currents with the exception that they are controllable and of steady value, the method has been found to be very useful in cathodic protection work. In developing this method, Dr. Pearson based his work upon the fact that the resistance through the earth between structures and the risistance between a structure and earth in any given location is constant and thus can be treated as such mathematically. Upon this basis underground structures can be considered as an electrical network permitting solution of problems relating to cathodic protection, interference, etc., by measuring the network constants at the proper location. Simple mathematical treatment of the data thus obtained will provide required solution most easily and quickly.

A brief discussion is given concerning the proper location of a ground bed in order to minimize the effect of interference on foreign structures. It is explained that when the ground bed is improperly located interference currents may be set up on the foreign structure which cannot be eliminated by the use of a bond between structures. There is generally a location at which a ground bed can be placed that will result in minimum interference current flow on foreign structures and which is in the direction permitting resolution by bonding. 8622

5.2.1, 4.5.3, 8.9.3

Current Requirements for Cathodic Protection of Pipe Lines. Marshall E. Parker. *Corrosion*, **11**, No. 4, 52-58 (1955) April.

The problem faced by the engineer seeking to cathodically protect a buried pipe line is to find the best and most economical way to drain from certain selected points on the line sufficient current to give adequate protection. Three basic methods to this end are placing the line under full protection, placing the line under partial protection and calculating the requirements for complete protection, both using temporary installations; and measuring the electrical characteristics of the line and calculating its behavior under various proposed systems.

The fourth method—an empirical estimate—is more important than its nature would indicate because certain assumptions based on observation and experience usually are helpful in arriving at a final conclusion.

Principal problems also faced by the engineer are those of securing electrical continuity where joints other than welded are used and insulating the line from other buried structures.

The author recommends a procedure involving steps such as: Determining static potentials, draining interrupted current from selected points and from data thus collected determining the relationship between polarization and driving voltage and attenuation of driving voltage; computing desired effect of combinations of drainage currents.

Also discussed are such questions as technique for making potential readings, various means of plotting data for best use, what constitutes "adequate" protection, where the electrode should be placed in making potential readings and other matters. 8615

5.2.1, 8.8.1, 1.2.2

The Application of Cathodic Protection to Chemical Plant. F. D. Murphy. *Ind. Chemist*, **30**, No. 357, 483-487 (1954) October.

Outlines the principles of cathodic protection; relative advantages and disadvantages of the use of sacrificial anodes and the use of applied current. Refers also to the limitations of cathodic protection; protection of aluminum and the economics of cathodic protection particularly in relation to its use with protective coatings.—BNF. 8585

5.2.2, 8.9.5

Check Costly Hull Corrosion. G. W. Kurr, Am. Smelting & Refining Co. *Marine Eng.*, **59**, No. 11, 57-60 (1954) Nov.

Recent annual docking of the Pure Oil, a T-3 tanker, showed effectiveness of magnesium anodes for under water hull surfaces. 53 anodes arranged in four groups on each side of the hull made up the cathodic protection system. After twelve months only major repair work on hull, apart from replacement of magnesium anodes, was touch up with vinyl paint of 5% of wetted hull area. Cause of corrosion is briefly discussed and design of system and insulating barrier are presented. Illustrations.—INCO. 8555

5.2.2, 8.9.5, 2.2.7

Anode Plate Protection. *Steel*, **135**, No. 20, 167 (1954) Nov. 15; *Modern Metals*, **10**, No. 10, 100-101 (1954) Nov.

Alcoa anode plate, a special aluminum alloy designed for cathodic protection of steel ship hulls in sea water, has been tested by installation on the *SS Alcoa Clipper*. Thirty-eight anodes cut from the anode plate, were bolted to the hull and rudder post of the ship in January, 1953. When the ship was drydocked in August, 1953, the steel on the stern frame, rudder post and rudder had retained its entire coat of pain and there was no indication of severe corrosion-erosion attack. The initial inspection revealed that the aluminum anodes were half consumed. In January, 1954, the anodes had been consumed to the point that they were ready for replacement but the hull was still in excellent condition. The plate is made in one standard size, 1 in. x 36 in. x 96 in. Other possible applications include: protecton of heat exchangers, storage tanks, various types of condensers and small metal-hulled boats.—ALL. 8657

5.2.3, 7.4.2

Cathodic Protection of Open Box Coolers. J. P. H. Zutphen. *Corrosion* 11, No. 1, 33-56 (1955) January.

Application of cathodic protection to exterior surfaces of tubes used to cool ammonia gas at pressures of 280 to 300 atmospheres is described. Because of space and other considerations, graphite anodes and impregnated graphite anodes were employed.

Heavy deposits of salts occurred initially on the areas nearest anodes but little on surfaces farther away because of close spacing of anodes and tubes. When current was reduced, deposits diminished and heat transfer rates improved. A sea-

sonal variation in the salt content of the cooling water resulted in an increase in resistance of the water and a corresponding decrease in the polarization of the tubes. This allowed corrosion of tubes farthest from anodes which was stopped when the anodes were relocated outward from tube surfaces to give better current distribution and output of selenium rectifiers was increased to return potential to design—850 millivolts.

Success of initial experiments with the coolers resulted in application of cathodic protection to new and larger coolers when plant capacity was increased. 8453

5.2.3, 8.9.3

Cathodic Protection Applied to a Large-Diameter Oil Pipe Line System. D. O. Griffith. *Corrosion*, 11, No. 3, 53-56 (1955) March.

Cathodic protection of a large-diameter pipe line transporting crude oil from West Texas to refineries located near the Houston Ship Channel presented many problems. The asphalt and coal tar enamel coated line was constructed of thin-wall, prestressed pipe. It traversed terrain with widely-varying characteristics, numerous road and river crossings, intersecting pipe lines and parallel lines in a common right-of-way. Distributed sources of limited current drainage combined with unidirectional bonds were desirable for protection in congested rights-of-way and metropolitan areas in order to minimize adjacent structure interference. Most of the cathodic protection installation was completed by the time the line was placed in operation. Installing protective units in locations convenient to pumping stations permitted cooperative inspection and maintenance by operating personnel. It was estimated that 99.9 percent of the trunkline piping was effectively insulated. A regular inspection schedule provides records for evaluating the efficiency of the protection and predicting any decline. 8649

5.3 Metallic Coatings

5.3.2

How to Make Iron Powder Components Resistant to Rust and Wear. R. P. Seelig, Chromalloy Corp. *Precision Metal Molding*, 12, No. 4, 103-106 (1954) April.

Chromalloy Corp.'s chromizing process provides a combination of rust protection, wear proofing and strengthening. Method involves a reaction between a chromium-rich gas and the ferrous surface followed by diffusion. Depending on the composition of the ferrous sintered material (method does not work on brass or bronze) and the type of treatment selected, two different results can be achieved. On low-carbon material (straight sintered iron, 1010 steel, etc.) a chromium iron alloy layer is formed which is rust resistant and possesses a considerable amount of ductility. This is called the Chromalloy case. On high-carbon material (sintered iron-graphite mixtures, 1095 steel, etc.) a chromium carbide layer is formed which is extremely hard and abrasion resistant. This is called the Chromacarb case. Physical properties of sintered iron are improved by Chromalloying. Illustrations.—INCO. 8651

5.3.2

Molybdenum Coatings Expand Uses of Metallising. A. P. Shepard. *Iron Age*, 173, No. 26, 105-107 (1954) July 1.

Sprayed molybdenum bonds well with-

out any surface preparation (except thorough cleaning) to the basis metal (steel, titanium, aluminum and magnesium alloys); provides excellent wear resistance and has been used, e.g., on textile spindles and Diesel locomotive crankshafts.—BNF. 8644

5.3.2

Tin as a Protective Material. (In Italian). G. Bianchi. *Metallurgia Italiana,* **46,** No. 4, 141-149 (1954) April.

The mechanism of corrosion of tin-coated copper and iron is considered, and the conditions under which tin inhibits corrosion studied. Testing methods for tin coatings are discussed, particularly the porosity test.—BNF. 8564

5.3.2

Electrolytic Nickel-Clad Plate Offers Low-Cost Corrosion Protection. S. G. Bart. Bart Mfg. Corp. *Iron Age,* **174,** No. 18, 87-89 (1954) Oct. 28.

New process recently developed by Bart Mfg. Co. makes available a low-cost clad material for fabricating assemblies which require corrosion protection. Pure nickel is deposited in thicknesses from 0.006-0.020 in. on any grade of mild steel. The material, called Lectro-Clad steel, can be roll formed, die formed, flame cut, sheared and welded. Several new methods for pickling, cleaning and etching are represented in this development. Nickel can be deposited at higher rates but 0.003-0.005 in./hour is optimum rate for smooth, pore-free surfaces. Nickel plate hardness is 140-160 Vhn; tensile strength is 50,000 psi.—INCO. 8487

5.3.2, 2.3.5

An Electrochemical Method for Evaluating Plated Coatings. W. J. Pierce and E. L. Pinner. Paper before Am. Electroplaters' Soc., 41st Ann. Conv., N. Y., July 13, 1954. *Plating,* **41,** No. 9, 1034-1042 (1954) Sept.

A means of evaluating electrodeposits with respect to their corrosion resistance is described. The electrolytic corrosion cell described supplied quantitative data in terms of numbers of perforations per unit area concerning the corrosion resistance of an electrodeposit. It may also reveal qualitative data regarding such things as plate inclusions or types of plate (bright, semi-bright, etc.) by means of distinctive forms of perforation. The test procedure itself consists in: 1) the plated surface is locked in the clamping fixture with the test cell in place. 2) Copper cathode is positioned in the Lucite cell and sufficient electrolyte is added to cover the cathode. 3) Electrical connections are made to the plated object and the copper cradle. The plated surface is the anode, the copper wire the cathode; 0.3 volt is applied to the system for a period of two, four, or more hours as necessary, depending on the nature of the plate and its thickness. 4) After the test period the plated surface is rinsed, and dried and the number and type of perforations determined.—ALL. 8677

5.3.2, 3.5.8

Stress in Chromium Deposits. J. E. Stareck, E. J. Seyb, and A. C. Tulumello. *Plating,* **41,** No. 10, 1171-1182 (1954) October.

Stress in deposits from the CR-110 self-regulating high-speed bath and in ordinary chromium deposits; correlation of cracking and stress; stress comparison for depositing alternate layers of low and high stress chromium; effect of baking. Determinations were made wtih the spiral contractometer, later by a rigid flat-strip method.—BNF. 8716

5.3.2, 3.7.3

Lead-Tin Alloy (Electrodeposited) Coating Improves Workability of Strip Steel. E. J. Roehl. *Iron Age,* **173,** No. 11, 140-142 (1954).

A 85:15 lead-tin alloy deposited from a fluoborate solution on to strip steel acts as a lubricant, reduces wear on dies and forming tools, eliminates or substantially reduces post-fabrication plating costs, has excellent solderability without chloride or acid flux, gives excellent corrosion-resistance and can be accurately controlled in thickness.—MA. 8638

5.3.2, 5.4.2

New-Low-Cost Coating Gives Mild Steel Good Corrosion Resistance. G. J. Harvey. N. Y. Testing Labs., Inc. *Iron Age,* **173,** No. 15, 125-127 (1954) April 15.

Fast, low-cost application of a nickel-phosphorus coating by the Niphos process is claimed to give mild steel corrosion-resistant properties comparable to stainless steels. In the process developed by N. Y. Testing Labs., an oxide of nickel is reduced on the coated surface at a temperature much lower than either the base metal or nickel. Nickel oxide, dibasic ammonium phosphate and water are combined to paste, paint or spray, consistency. By varying the constituents, the resulting alloy will vary in percentage of phosphorus and will vary the physical properties of the coating. Application can be made by brushing, dipping or spraying. Any thickness can be applied to all shapes and sizes of objects. Illustrations. —INCO. 8405

5.3.2, 5.4.5

Organic Finishes on Electrodeposits. E. C. J. Marsh. *Electroplating,* **7,** No. 5, 187 (1954); disc., *Ind. Finishing* (Brit.), **6,** No. 72, 816-818 (1954).

Suitable treatments and coatings for application to zinc- and cadmium-plated objects are suggested. Etch primers are recommended for use with nickel, chromium, silver and gold.—RPI. 8732

5.3.2, 5.8.2

Improvement of the Corrosion Resistance of Tinplate by a Chemical Treatment. S. C. Britton and R. M. Angles. *J. Applied Chem.,* **4,** No. 7, 351-364 (1954) July.

Corrosion of tin coating by sodium hydroxide solution is retarded by solutions of sodium chromate (about 3g./1. in a 1% sodium hydroxide solution); tin plate remains bright and becomes more resistant to atmospheric corrosion, oxidation on heating and staining by materials containing sulfur; very dilute solutions of sodium chromate (up to 0.15%) accelerate the corrosion of tin in a 1% sodium hydroxide solution.—BNF. 8567

5.3.2, 6.4.2, 3.5.6

The Diffusion of Addition Elements, Particularly Copper, in the Cladding of Light Alloys. (In French). M. Renouard. *Rev. Met.,* **51,** No. 6, 419-424 (1954) June.

The coefficient of diffusion of copper from Duralumin into the aluminum cladding was measured; it was found to vary considerably between one sheet and another. The seriousness of the diffusion and methods for reducing it, are discussed.—BNF. 8718

5.3.2, 8.8.1

Nickel- and Monel-Clad Steel in the Chemical Engineering Industry. E. J. Bradbury. Paper at 5th Symposium on Materials of Construction for the Chemical Industry (Clad Materials): sponsored by Dutch Chemical Soc. and Royal Dutch Inst. Eng. Nov., 1953. *Ingenieur,* No 16, 18, 20-22 (1954); *Chem. Tech.,* No. 4/7, 16-24; disc., 24-25 (1954).

Detailed information on thermal, physical, mechanical and corrosion-resisting properties of nickel, low-carbon nickel and Monel with reference to use as claddings in construction of chemical plant. Data on fabrication and on design of plant, extracts from pressure vessel codes, allowable stress values in tension for nickel, Money and carbon steel and approximate limiting service temperatures in sulfur-free and sulfurous atmospheres and in halogen acids are given. Behavior in oxidizing atmospheres and resistance to molten metals are included. Corrosion-resistance in contact with fresh and salt-water, neutral and alkaline salts, acid salts, oxidizing acid and alkaline salts, sulfuric acid, hydrochloric acid, phosphoric acid, oxidizing acids, alkalis (detailed results of tests in caustic soda at various temperatures and concentrations for nickel, Monel, 70/30 cupro-nickel, arsenical copper, 15/11 nickel-chromium steel and 18/9 chromium-nickel steel; test data for nickel in evaporation of caustic soda from 73-96 with and without chlorate) is discussed.—INCO. 8503

5.3.4

How to Finish Metal Products by Vacuum Metallizing. J. G. Seiter. *Products Finishing,* **18,** No. 8, 38-48 (1954) May.

After a brief discussion on the advantages and applications of vacuum metallizing, a detailed account of the process is given, illustrated by a description of the zinc alloy die cast horns, manufactured by Yoder Manufacturing Co., which are given a vacuum metallized aluminum finish.—ZDA. 8648

5.3.4

Hot Dip Galvanizing. Parts I, II, and III. K. S. Frazier. *Steel,* **134,** 102-103, 98-99, 138-139 (1954) Feb. 22, Mar. 1, Mar. 8.

Part I. Deals chiefly with coating thickness. The life of a zinc coating on steel under given atmospheric conditions is directly proportional to the thickness of the coat.

Part II. Control of timing, temperature and cleanliness of work automatically improves uniformity and product quality. Photograph, diagram, graphs.

Part III. Deals with materials and methods. To ensure the advantages of controlled hot dip galvanizing, all phases of base materials and preparatory processes must be thoroughly investigated. For example, low-carbon, open hearth steels are most suitable for hot dip galvanizing but even they vary considerably, resulting in a coating that may be too porous or too dark. 8523

5.3.4, 3.7.3, 1.6

Electroplating and Corrosion Prevention. E. Molloy, Editor. Book, 278 pp., 1954. London: George Newnes, Ltd.

This book consists of a hodge-podge of information connected with electroplating and metal finishing processes, supported by large numbers of illustrations, most of which are not explained or referred to in the text. Many of the statements are incorrect or record practice years out of date and much of the rest is so vague and lacking in essential details as to be useless except where it has obviously been taken direct from manufacturers' literature.

No author is named, but the book is

stated to have been "edited by E. Molloy," apparently from information provided by supply firms and some miscellany of metal-finishing tips and wrinkles. It seems all to obvious that Mr. Molloy has little practical knowledge of metal finishing and has done a disservice to his collaborators by producing a thoroughly uncritical and unreliable account of what are undoubtedly efficient processes.

It is most unfortunate that a publisher, most of whose books are of immense help to engineers, technicians, and artisans, should have produced such a physically attractive, but technically useless, book. —MA. 8603

5.3.4, 5.3.2

Metallizing for Corrosion Prevention. A. P. Shepard and R. J. McWaters. *Corrosion*, **11**, No. 3, 29-32 (1955) March.

Problems and techniques connected with the spraying of molten metal on iron and steel to prevent corrosion are surveyed, including surface preparation, bonding coat, organic sealers and the relative merits of the various metals sprayed. Characteristics of zinc and aluminum coatings are discussed and recommendations are made for selection vs. environment anticipated. A list of recommendations for specific applications includes ship's hulls, oil tanker interiors, fresh water tanks, marine atmospheric exposures, railroad bridges, steel piling, industrial atmospheres, exhaust stacks and mufflers and river lock gates. 8579

5.3.4, 5.9.4, 6.5

Can Powdered Metal Parts Be Surface Finished? A. E. Schellschmidt. *Precision Metal Molding*, **12**, No. 9, 77-78 (1954) Sept.

Iron and brass camera parts made by powder metallurgy are finished by phosphating and satin chromium plating respectively.—BNF. 8678

5.3.4, 6.2.5

Preparation of Corrosion-Resisting Steel for Cadmium Plating. Ministry of Supply D. Mat. RD (A) Memorandum No. 3, 1954, 2 pp.

Recommends a method of preparation to facilitate plating of stainless steels: degrease, alkali clean, sulfuric acid pickle, rinse, nickel strike, rinse and plate with cadmium.—BNF. 8658

5.4 Non-Metallic Coatings and Paints

5.4.4, 5.9.2

Modern Industrial Paint Strippers. R. M. Operowsky. *Plating*, **41**, No. 8, 915-920 (1954).

The different types of paint strippers are discussed. Alkaline strippers are cheap and easy but are slow, will tarnish brass and etch zinc, while they will not deal satisfactorily with pigments. Acid strippers, e.g., concentrated sulfuric acid are fast and clean acting but are corrosive and hygroscopic. Thinners are the cheapest paint removers but can only be used prior to stoving and for some air dried finishes. Cold strippers are expensive but are the most popular as they are fast, have a high flash point, a minimum of attack on the metal and the work is left clean. Hot solvent emulsion strippers are based on phenol derivatives and an emulsifier and are best for stripping alkyl, melamine, phenolic, epoxy and urea type coatings in large production stripping.—EL. 8675

5.4.2, 3.5.9

Two New High Temperature Coatings. A. PECHMAN. Ryan Aeronaut. Co. *Materials & Methods,* **39,** No. 4, 94-96 (1954) April. See Also: Ryan Develops Ceramic-Liner Techniques. *Aviation Week,* **60,** No. 17, 38, 40, 42 (1954) April 26.

An experimental nickel magnesia cermet can be flame sprayed. Applied to stainless steel, Inconel and other high-temperature alloys, it will withstand temperatures up to 3500 F for limiting periods.

Latest ceramic coating developed by National Bureau of Standards, A-418, has retarded occurrence of oxidation, carbon absorption and corrosion attack usually experienced in application; possibility of arc welding through coating. 8595

6. Materials of Construction

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.8, 5.8.2

Sodium Fluosilicate as an Anticorrosive for Lead. (In Dutch). F. M. BOSCH AND R. ROELS. *Tech. Wetenschap. Tijdschr.,* **22,** 247-248 (1953) November.

An iron-lead couple immersed in various waters was used to determine whether addition of sodium fluosilicate inhibitor is effective in preventing the corrosion of lead. Five waters were studied, viz., completely demineralized water (three times distilled), with and without carbon dioxide; demineralized water containing carbon dioxide plus 178 mg. fluosilicate per liter; and Permutit-softened industrial water, with and without addition of fluosilicate. Samples were taken after 1, 3, 9 and 27 hours and the concentration of dissolved lead was determined polarographically.

The presence of sodium fluosilicate did not diminish corrosion in waters where the normal protective carbonate layer was absent or inadequate.—PDA. 8349

6.3.9, 5.3.2

Oxidation-Resistant Coatings for Molybdenum. Quarterly Progress Report No. 3 for the Period April 2, 1953—July 1, 1953. J. R. BLANCHARD. Climax Molybdenum Co. of Michigan, Contract AF 33(038)-16197, 11 pp.

Nine different single-layer coatings protected molybdenum from oxidation at 1800 degrees F for at least 500 hours. The most consistent results were obtained with coatings containing aluminum and the following alloys: nickel-silicon, chromium-silicon and iron-chromium-silicon. Two single-layer coatings protected molybdenum from oxidation in air at 1800 degrees F for approximately 100 hours, during which exposure the coated specimens were stressed sufficiently to produce elongations of approximately 5 percent in the gage sections. The coatings were Colmonoy No. 5 and Colmonoy No. 6. (auth).—NSA. 8339

6.3.9, 5.3.2

Oxidation-Resistant Coatings for Molybdenum. Quarterly Progress Report No. 2 for the Period January 2, 1953—April 1, 1953. J. R. BLANCHARD. Climax Molybdenum Co. of Michigan, Contract AF 33(038)-16197, 9 pp.

Two single-layer sprayed coatings protected molybdenum from oxidation at 1700 degrees F for at least 500 hours, One two-layer sprayed coating protected molybdenum from oxidation at 1800 degrees F for at least 500 hours. One three-layer sprayed coating and one single-layer sprayed coating protected molybdenum exposed to air at 1800 F for approximately 100 hours, during which exposure the coated specimens were stressed sufficiently to cause elongations of over 2 percent in the gage sections. (auth).—NSA. 8341

6.3.11, 7.7

Hardenable Silver Alloy. *Elec. Mfg.,* **53,** No. 6, 154, 156 (1954) June.

Silver-magnesium-nickel is a hardenable high silver alloy furnished in soft, ductile strip or wire. In the hardened condition, the silver alloy has good spring properties, excellent corrosion resistance and high thermal and electrical conductivity. It can be soft- and silver-soldered without affecting the temper. Physical properties include: hardness to 70 (Rockwell 30 T); and modulus of elasticity, 12.5 x 12⁶. It can be used for electrical contacts, contact arms and wipers, tube clips and other applications. —INCO. 8095

6.3.19, 6.3.14, 5.9.4

Recent Methods for the Protection of Zinc and Tin. H. ANDERS. *Werkstoffe u. Korrosion,* **3,** No. 12, 460-461 (1952).

Protection of zinc surfaces. Cause of difficulties encountered. Chemical methods of surface protection of zinc involving the production of chromate coatings; two-stage treatment developed by Metallgesellschaft. Treatment of zinc alloys in potassium ferrocyanide bath and in an alkaline chromate solution, respectively. Anodic methods: Use of solutions of ferrocyanide, ferricyanide, permanganates, chromates, oxalates, etc. Protection of tin surfaces: Anodic oxidation in dilute ammonia solutions; anodic blackening of tin and tin alloys with solutions containing phosphates or ferricyanides. Translation available: Henry Brutcher, P. O. Box 157, Altadena, California. 7936

6.3.20, 1.6, 5.9.4, 3.6.8

Studies on the Anodic Polarization of Zirconium and Zirconium Alloys. MARIO MARAGHINI, GEORGE B. ADAMS, JR., AND PIERRE VAN RYSSELBERGHE. Oregon Univ., U. S. Atomic Energy Comm., (AECU-2797), Sept., 1953, 61 pp.

The anodic polarization of zirconium and of some of its alloys was studied in several different aqueous electrolytes. In chloride solutions, corrosion potentials below that of oxygen evolution were established, but the addition of nitrate ion in the ratio of 3 to 5 to chloride ion brings the potential above that of oxygen evolution. The formation of the oxide film along the three portions of the potential-time curve (initial rapid increase, evolution of oxygen at practically constant potential, final rapid increase) was studied in detail and quantitative information about local currents and the efficiency of the film-building process was obtained. (auth).—NSA. 7913

6.3.20, 3.6.8, 3.8.4

Progress Report on Electrochemical and Polarographic Studies on the Corrosion of Zirconium in the Presence of Various Aqueous Media. PIERRE VAN RYSSELBERGHE. U. S. Atomic Energy Commission Rept., AECU-2385, 3 pp., January 23, 1953.

Oxygen consumption was not observed on zirconium sheet treated with air-saturated 2-7 M hydrochloric acid. Cathodically polarized zirconium gave polarization potentials too variable to detect hydrogen peroxide. Potential vs. time studies indicate that an oxide surface film is formed except in hydrochloric acid media, where hydrogen may be chemisorbed or the hydride formed. Other solutions tested were 1 N potassium chloride, 1 N sodium sulfate and water (distilled). Polarization curves were obtained. In 1 N sodium sulfate a non-conducting film is formed on the zirconium anode. 7974

6.3.20, 3.7.2

Effect of Hydrogen on Mechanical Properties of Zirconium and Its Tin Alloys. G. T. MUEHLENKAMP AND A. D. SCHWOPE. Battelle Memorial Inst., BMI-845, June 30, 1953, 16 pp.

Hydrogen, in excess of 20 ppm in zirconium and its tin alloys makes these materials behave in a brittle manner in the room-temperature notched-bar impact test. Increasing hydrogen contents, up to 500 ppm increase the transition temperature. It lowers the tensile ductility slightly and has no apparent effect on the tensile-strength properties. The embrittling effect is eliminated by water quenching from above 600F, if the hydrogen content is less than 60 ppm. The hydrogen content may be lowered sufficiently by vacuum annealing to make zirconium tough in the notched-bar impact test at temperatures as low as —80C. (auth).—NSA. 7918

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2, 3.2.2

Intergranular Corrosion of High Purity Aluminum in Distilled Water at 100°C and 150°C. M. J. LAVIGNE. Department of Mines and Technical Surveys (Canada), Publ. ES-11, July 8, 1953, 8 pp. *Metal Progress,* **64,** No. 3, 84-86 (1953) Sept.

Corrosion tests carried out by the author in distilled water at 150C on some high-purity aluminum indicated that in some cases the intergranular attack did not occur with high-purity aluminum in the unannealed condition but always occurred in the annealed condition. Etch-pit analyses of samples which resisted the attack revealed that the orientation of the crystals in the contiguous bands was very similar. Other experiments in water at 150C suggested that the high-purity aluminum with a 0.1% silicon addition, annealed or unannealed, does not suffer intergranular attack. A metallographic examination of the tested samples showed that there is a low degree of misfit between the adjacent lattices. The results seem to indicate that metallurgical factors have great bearing on the corrosion resistance of high-purity aluminum and when interpreting corrosion results its texture should be considered. The unpredictable behavior of the annealed high-purity aluminum samples indicates that processing variables other than annealing have a marked influence on the corrosion resistance; e. g., the poor corrosion properties of annealed samples of high-purity aluminum and the corrosion resistance of all the samples of the aluminum-silicon alloy. (auth).—NSA. 8015

6.4.2, 3.7.2, 3.2.2

Pitting Corrosion Characteristics of Aluminum: Influence of Iron and Silicon. P. M. AZIZ AND HUGH P. GODARD. *Corrosion*, 10, No. 9, 269-272 (1954) Sept.

This work was undertaken to determine the influence of iron and silicon upon the pitting characteristics of aluminum. Iron and silicon in amounts from 0.05 to 0.7 percent, alone and in various combinations was added to commercial purity (99.75 percent Al) and super purity (>99.99 percent Al) aluminum. The addition of iron at any level increases the pitting probability of super purity aluminum whereas no significant increase occurs for the commercial purity aluminum. The addition of silicon to super purity aluminum in amounts of 0.3 percent and greater increases the pitting probability whereas no significant increase occurs for commercial purity aluminum. The probability of pitting of commercial purity aluminum is 2.5 times that of the super purity aluminum at corresponding iron and silicon levels. The addition of iron and/or silicon increases the rate of pitting of super purity aluminum but has little effect on the rate of pitting of commercial purity aluminum. 7995

6.4.2, 3.8.3, 5.9.4

The Passivation of Aluminium Immersed in Nitric Acid. I.—IV. (In French). Jos. PATRIE. *Rev. Aluminium*, 29, No. 194 (1952) 431-437; *ibid*, 30; No. 195, 196 & 197; 5-11, 45-54, 87-96 (1953).

The oxidation of aluminum occurs under a variety of conditions, and Patrie shows that by means of a corrosion diagram one can establish conditions of pH and voltage under which passivation occurs either of the metal itself or as a result of the growth of an oxide film. After consideration of the thermodynamics of the oxidation of aluminum by aqueous solutions, experiments were made to establish the changes in potential of aluminum immersed in nitric acid solutions of various pH values over a period of time. Further studies were made of the polarization of aluminum by a galvanic couple (using graphite) and by an applied potential. These showed that oxide films can form on aluminum only if the potential of the metal is greater than that of the oxygen evolved and even then only very thin films were formed. When a galvanic couple was made between graphite and aluminum immersed in concentrated nitric acid, the potential was insufficient to form an electrolytic oxide film, as the reaction potential of the aluminum was not high enough. By the addition of an oxidizing agent such as CrO_3, $K_2Cr_2O_7$ or MnO_2, films could be produced on aluminum, since the potential of the graphite was raised and the anodic potential of the aluminum exceeded that of the discharged oxygen.

Studies were then made of the various factors influencing this process, such as temperature, time and nitric acid: chromium oxide ratio and their effect on the cell potential and rate of growth of the oxide film, as well as the influence of alloying elements on the current produced and the rate of film formation. The alloys containing magnesium or Mg_2Si are favored in addition to high-purity aluminum. The nature of the film has been studied by electron diffraction: it is moderately ductile and absorptive. The account concludes with some studies on the effect of the accumulation of chromium and aluminum nitrates on the performance of the bath. By the addition of fresh chromium trioxide and nitric acid after periodic checks, the efficiency of the bath can be maintained. Using a bath of 30 g./l. chromium oxide in concentrated nitric acid, a surface area of 25-50 dm.²/l. could be treated. After treating 40 dm.²/l, it was found that 10 g./l. chromium oxide had been lost and 63 g./l. nitric acid. Electrolytic polishing can be also produced by coupling the aluminum anode to a graphite cathode in a mixture of 800 cc phosphoric acid, 50 g. chromium oxide and 200 cc water at 80-90C.—MA. 7944

6.4.2, 4.6.1, 3.2.2

Corrosion of Aluminium Alloys in Supply Waters. F. C. PORTER AND S. E. HADDEN. *J. Applied Chem.* (London), 3, No. 9, 385-409 (1953) Sept.

Studies carried out by the British Non-Ferrous Metals Research Association on the corrosion of aluminum and aluminum alloys in a wide range of still and slowly moving supply waters are reported, with special reference to the initiation and development of nodular pitting (i. e. the formation of mounds of insoluble $Al_2O_3 \cdot 3H_2O$ beneath which pitting takes place). The effects of water composition were more pronounced than those of alloy composition, the attack in general being more severe in the harder waters. The requisite combination of water constituents for the occurrence of nodular pitting were found to be calcium bicarbonate, chlorides, copper salts and dissolved oxygen and when these constituents were present together in fair quantity a very slight amount of copper in solution was sufficient to cause severe attack; in synthetic waters not containing all the four constituents mentioned, pitting, when it did occur, was not of the nodular form. A mechanism for the nodular attack is presented.—MA. 7986

8. Industries

8.5 Group 5

8.5.3

Solving Corrosion Problems in the Paper Industry with Plastics. RAYMOND B. SEYMOUR AND GEORGE P. GABRIEL. *Paper Mill News*, 76, 98, 100, 102, 108, 146 (1953) August 22.

Discusses coatings, membrane linings and chemical resistant cements.—BTR. 7890

8.6 Group 6

8.6.1

Washer for Compact Living. W. C. BELL AND J. H. BEACH. *Elec. Mfg.*, 53, No. 2, 114-120 (1954) Feb.

Discusses small compact clothes washer now redesigned for improved appearance and lower cost production. Major design problem was to find a corrosion resistant material for the tub without use of a nickel-bearing alloy. Original design used 18-8 stainless. Aluminum with a surface sealing treatment employing an anodizing process was used. Photographs and diagrams.—INCO. 8044

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